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THE DESIGN, DEVELOPMENT, AND TESTING OF AN AIRCREW RESTRAINT SYSTEM FOR ARMY AIRCRAFT

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June 1972

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FORT EUSTIS, VIRGINIA

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13 ABSTRACT

The purposes of this study were to design, test, and optimize an aircrew restraint system for a forward-facing, nonejection seat for Army aircraft based on the criteria contained in Chapter 4 of USAAMRDL Technical Report 71-22, "Crash Survival Design Guide", October 1971, and to prepare a proposed draft Military Specification.

A literature search was conducted to determine the state of the art in restraint system development and injury potential prediction technology. The dynamics of an occupant restrained in an integrally armored crew seat were analyzed to establish restraint system performance trends as a function of pertinent variables.

Based on the information gathered and the Design Guide criteria, a restraint system was designed. Restraint systems and components were fabricated, and static and dynamic tests were conducted. A series of seven static tests was conducted to determine the elongation at design loads of the restraint system components and the associated hardware adjusted for a 95th percentile occupant. Failure loads and the restraint member elongations at these loads were also obtained. The results of static tests were used to define an optimum width for the lap belt.

For the dynamic test, the restraint system was used to secure a 95th percentile anthropomorphic dummy, equipped with helmet, body armor, survival kit (vest type), and components, to a fixture-type seat. The restraint system was loaded in the longitudinal direction with the seat rotated to induce a lateral load component. The dynamic test provided system performance demonstration and empirical data for the overall evaluation of the aircrew restraint systems.

The information gathered from this study was used to prepare a draft proposed Military Specification in the FSC 1680 series.

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This report was prepared by Dynamic Science (the AvSER Facility), a Division of Marshall Industries, under the terms of Contract DAAJ02-70-C-0065. The technical monitors for the program were Messrs. W. J. Nolan and G. T. Singley, III, of the Safety and Survivability Division, Eustis Directorate.

Within the past several years, aircraft crashworthiness has assumed a position of importance among those responsible for the establishment of aircraft design criteria. As a result of this increased emphasis on the importance of providing occupant protection in the crash environment, the survival rate in aircraft accidents has improved significantly. However, injuries and fatalities attributable to aircrew restraint system inadequacies continue to occur in Army aircraft survivable accidents.

Research and development efforts have resulted in the formulation of criteria applicable to the design of improved aircrew restraint systems. These criteria are contained in USAAMRDL Technical Report 71-22, "Crash Survival Design Guide". Much of this work has been analytical rather than empirical, and the feasibility and practicability of the design criteria have not been established through comprehensive testing.

This report contains the results of a program that involved the validation of TR 71-22 aircrew restraint system design criteria through a state-of-the-art survey, detail design, fabrication, and static and dynamic testing. In addition, a proposed draft military specification was prepared by Dynamic Science for subsequent publication by the Army.

Not all of the conclusions and opinions expressed by the contractor are concurred in by the Eustis Directorate at this time. While the results of future work may substantiate the contractor's position, it is felt that more work is necessary to adequately resolve the conflict between published criteria and the findings of this investigation.

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INTRODUCTION

BACKGROUND

For a number of years, the U. S. Army has been engaged in research and development to improve aircraft safety and survivability. As a better understanding of the crash environment evolved, experimental programs were conceived and conducted to fill gaps and verify general survivability factors about the environment. The basic problem has been how to protect the occupant in this environment. Therefore, human tolerance in the environment needed definition (more specifically, tolerance to high rates of acceleration onset and acceleration magnitude). Data generated by various investigators were assimilated and summarized in a form wherein human tolerance of the crash environment could be viewed.

With this knowledge of the crash environment and human tolerances, it then became necessary to define criteria for designing systems that would protect the occupant(s). Consideration was given to limiting the crash loads imposed on the occupant, restraining the occupant, maintaining occupant compartment integrity, and protecting the occupant from post-crash fire hazards. The problem of adequate emergency egress time was also studied. A wealth of data were generated and used as criteria for designing crashworthy systems such as the crash-resistant fuel systems which will ultimately be retrofitted on the majority of the Army aircraft. Criteria applicable to crashworthy crew seats, restraint systems, litter systems, cargo tie-down systems, and airframe concepts also evolved from the data.

Initial studies of personnel restraint systems for Army aircraft explored the feasibility of improving seat belt and shoulder harness installations to reduce the severity and frequency of injuries and fatalities in potentially survivable accidents. The design and strength of restraint harnesses (seat belt, shoulder belt, and tie-down straps) were also studied. The results of restraint harness studies were reported in Reference 1, and the studies concerning the manner in which the restraint systems are attached in the aircraft are reported for specific aircraft in References 2 through 7.

As studies about personnel restraint systems continued, it became apparent that the restraint harnesses in use in Army aircraft did not possess sufficient strength to hold the occupant in the seat even when the seat and/or the seat tie-downs survived the crash. This resulted in severe injuries or fatalities to the occupants. Excessive elongations resulting from

the use of improper materials in restraint systems also caused injuries. System designs that did not provide occupant restraint in all directions also contributed to injuries.

Since these restraint systems were designed to meet the requirements of then current specifications, it was apparent that the specifications were inadequate. Design criteria were established in all areas of crashworthiness and documented in 1967 in USAAVLABS Technical Report 67-22, "Crash Survival Design Guide." An entire chapter was devoted to restraint harness for passenger and cargo.

CURRENT PROGRAM

The program discussed in this report was initiated in mid-1970 to design, test, and optimize an aircrew restraint system for a forward-facing, nonejection seat and to prepare a proposed draft Military Specification defining this system. The restraint system was to conform to the strength and performance criteria of Reference 8. The restraint system was to provide protection for all occupants from the 1st to the 99th percentile Army aviator from all aspects of the 95th percentile crash environment for light fixed-wing and rotary-wing aircraft as specified in Chapter 1 of Reference 8. Design efforts were to consider retrofit requirements of existing aircraft seats as well as new seats, including crashworthy armored crew seats.

In conducting the program, previous and current technologies were first reviewed to establish state of the art in restraint system development and injury potential prediction technology. Analyses to determine restraint system performance trends as a function of pertinent variables and a restraint system concept trade-off were conducted to establish the overall configuration of the personnel restraint harness to be designed. Prototype restraint harnesses were designed, and restraint systems and components were fabricated. Static testing was accomplished through individual testing of each restraint harness component along with the associated connecting, adjusting, and tie-down attachment hardware.

After a series of seven static tests was completed, a dynamic test was performed. The restraint system was used to secure a 95th percentile anthropomorphic dummy, equipped with helmet, body armor, survival kit (vest type) and components, to a simulated seat. The dynamic test demonstrated system performance and provided empirical data for the overall evaluation of the aircrew restraint system.

Advanced features of the resultant restraint system include increased lateral restraint through the use of a double-strap lap-belt tie-down, side straps, and reflected shoulder straps. Increased torso and head restraint was also achieved through the use of the reflected straps.

LITERATURE SEARCH

INTRODUCTION

The literature search began with a letter request to restraint system manufacturers and several Government agencies. This request explained the need for the restraint system information sought and solicited cooperation in the program.

The information received from the manufacturers and Government agencies was recorded on a form in the following categories:

1. Restraint Configuration
2. Fittings and Attachments
3. Design Considerations
4. Materials
5. Inertia Reels
6. Human Tolerance and Injury Criteria
7. Occupant/Restraint System/Seat System Interaction
8. General Comments

GENERAL

All of the documents reviewed during this program are listed in the Bibliography. In addition to the letter requests to restraint system or component manufacturers and Government agencies, two data and information-gathering trips were made.

In recent years, and especially since restraint systems became mandatory in passenger automobiles, a lot of effort has been sponsored by the National Highway Traffic Safety Administration (NHTSA), formerly the National Highway Safety Bureau (NHSB). Therefore, NHTSA technical reports, National Bureau of Standards (NBS) test reports, and Society of Automotive Engineers (SAE) technical papers were good sources of information. Because of the emphasis on passive restraint systems by NHTSA, very little improvement has been made in the automotive applications of some of the more advanced active restraint systems used in military aircraft today. Perhaps the area that has gained most from the NHTSA-sponsored work is impact injury tolerances.

Summaries of the most current information available concerning human impact tolerances are contained in papers by Snyder[9] and the SAE Human Factors Biomechanics Subcommittee.[10] A major effort to compile a comprehensive report and evaluation of the state of the art of the knowledge of human impact tolerance was completed for the SAE FISITA 1970 International Automobile Safety Conference held in Brussels, Belgium, and Detroit, Michigan (updated by Snyder in August 1970).[11] This work includes 446 references of impact studies and summary tables of the results of all known investigations of animal and human deceleration tests. It presents detailed and comprehensive information and should be consulted for other references or work in specific areas of impact (also see Reference 12). Among many excellent papers prepared by Dr. J. P. Stapp, his "Human Tolerance to Severe, Abrupt Deceleration,"[13] and "Voluntary Human Tolerance Levels,"[14] are particularly useful and authoritative.

TOLERANCE AS A FUNCTION OF RESTRAINT SYSTEMS

It has been observed in field investigations of aircraft accidents that many occupants receive fatal injuries although the cabin structure often remains essentially intact. Hasbrook[15] has pointed out in a study of 913 light aircraft accidents that, while 56.1 percent of the cabin structures remained "intact to distorted," 478 (29.4 percent) of the occupants were killed or received serious injuries. Many such accidents might have been survivable had the occupants been better protected within their environment. Reference 9 provides the basis for much of the discussion in this section.

Injury Patterns

Identification of the region of the body most frequently injured in aircraft crashes provides a va__d basis for assigning priorities of protection needed. Through quantitative analysis of the combined data of a great number of survivable lightplane accidents,[16] certain injury patterns were established which may be considered typical for this category. Figure 1A shows the location of injuries received by 800 survivors of light-plane crashes. Figure 1B shows the percentage of these injuries which were considered dangerous to life.

Based on the information in Figure 1A, the frequency of injuries in certain body areas indicated a peripheral trend, i.e., the areas farthest away from the seat belt region are injured most often. This is caused by lack of restraint which allows the head and the extremities to gain more momentum during impact. Forcible contact with sharp or unyielding objects within striking range will invariably result in injuries.

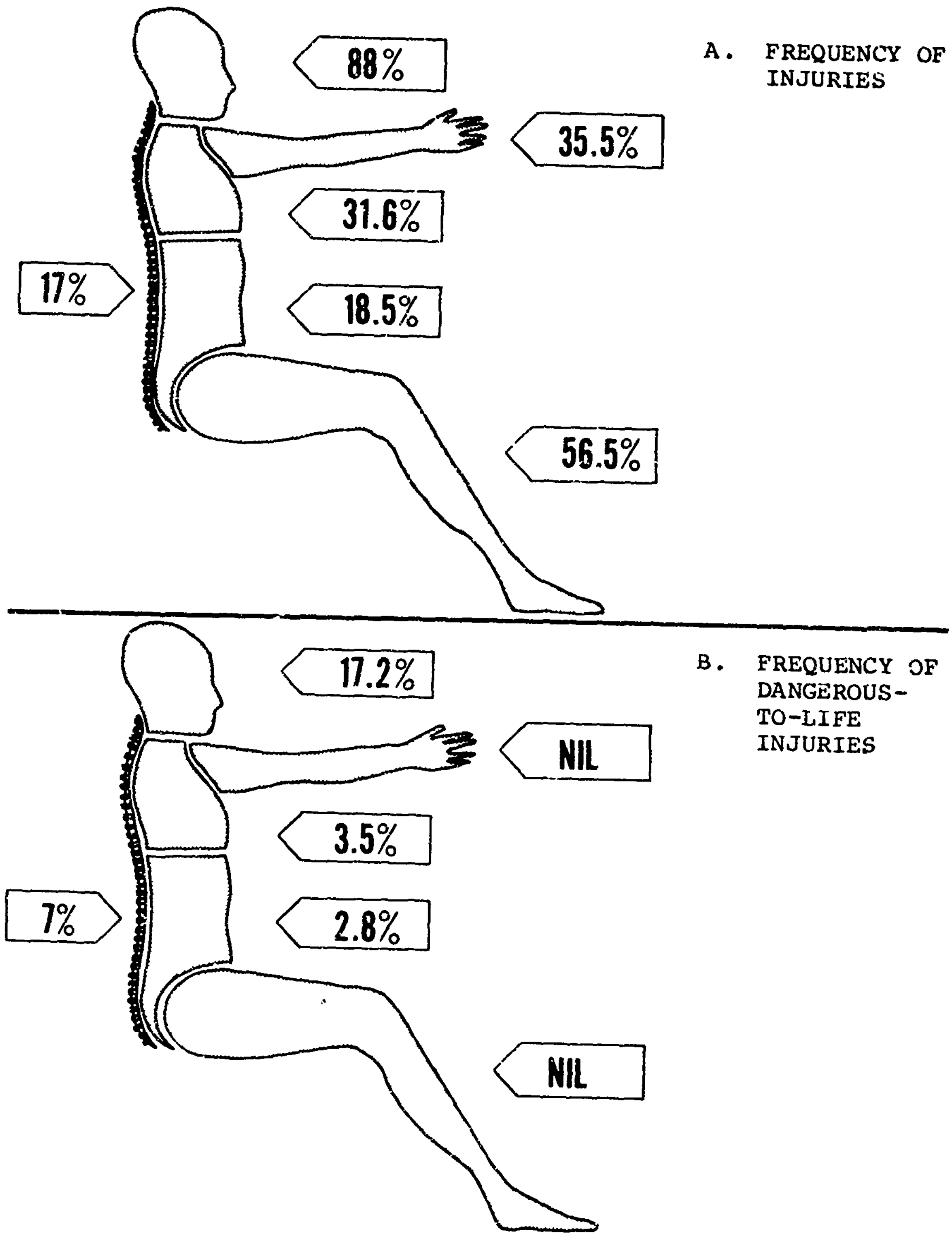


Figure 1. Injury Patterns.

The obvious remedy for this situation is more restraint of exposed body areas and/or delethalization of the occupant environment.

Examination of Figure 1B indicates that a crash-safety program for light planes should assign priority to those efforts which will provide protection of the head and spine.

The conclusions drawn after examination of crash injury data spanning the past decade indicate that, irrespective of the type of aircraft, the head and spine must be protected from high crash forces if the occupant is to survive. Additional consideration must be given to restraining the extremities if the occupant is expected to exit the aircraft safely in the immediate postcrash period. Inflatable restraint systems appear to hold promise for increasing the restraint of the head, spine, and extremities; however, the disadvantages mentioned later for inflatable restraints must also be considered.

Whole Body Impact Tolerance

Historically, aviation medicine has been primarily concerned with human tolerances of the body as a whole. The development of restraint systems; studies of ejection, blast, and escape; and crash impact protection and survival have all focused on the human organism as an entity.

Physiologically, the subject's body orientation can be described in relation to the force; and, since 1961, terms using the X, Y, and Z axes have been recommended by the Biodynamics Committee of the Aerospace Medical Panel (AGARD) as a universal method of standard description for simple uniaxial accelerations.[17] This is shown in Table I.

Most impact work descriptively identifies accelerations as being forward, rearward (or aft), headward, footward, to the right or to the left; however, some military investigators use the vernacular description which relates "eyeballs" movement in inertial response to the applied acceleration. Since "off-axis" impacts may occur, a three-dimensional system is sometimes used in terms of roll, pitch, and yaw relative to horizontal flight on a polar coordinate system. In this system a seated aircraft occupant facing forward would be 0-0-0, while a 0-23-90 orientation describes a $+G_y$ (or eyeballs left), right side impact, 23 degrees back from the perpendicular. Note that when the subject is forward-facing to the direction of force, the symbol $-G_x$ is used, while $+G_x$ indicates rearward-facing into the direction of the impact. X-axis terms are opposite those used in the long-term acceleration studies.

TABLE I. IMPACT TERMINOLOGY; COMPARATIVE TABLE OF EQUIVALENTS[17]

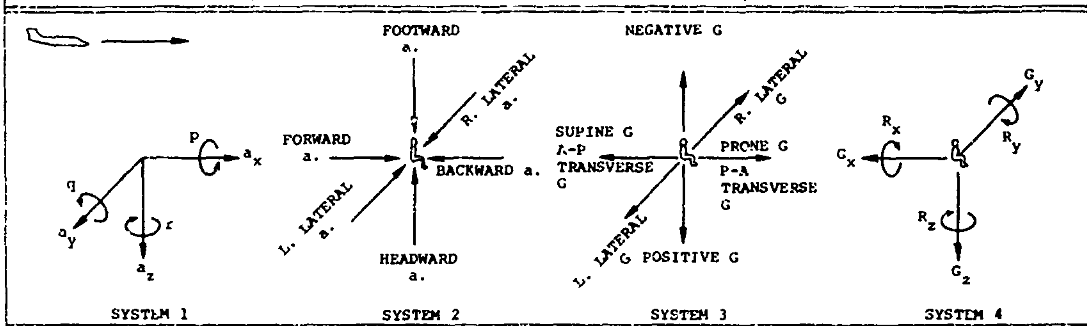


	Table A		Table B		
	Direction of Acceleration		Inertial Resultant of Body Acceleration		
Linear Motion	Aircraft Computer Standard (System 1)	Acceleration Descriptive (System 2)	Physiological Descriptive (System 3)	Physiological Standard (System 4)	Vernacular Descriptive
Forward	$+a_x$	Forward Acceleration	(1,2) Transverse P-A G Prone G Back to Chest G	$-G_x$	Eyeballs in
Backward	$-a_x$	Backward Acceleration	Transverse A-P G Supine G Chest to Back G	$+G_x$	Eyeballs out
Upward	$-a_z$	Headward Acceleration	Positive G	$+G_z$	Eyeballs down
Downward	$+a_z$	Footward Acceleration	Negative G	$-G_z$	Eyeballs up
To Right	$+a_y$	Right Lateral Acceleration	Left Lateral G	$+G_y$	Eyeballs left
To Left	$-a_y$	Left Lateral Acceleration	Right Lageral G	$-G_y$	Eyeballs right

Primary vector acceleration axes are defined to the individual's spinal axis, and vector directions refer to the inertial response of the individual. Note that in deceleration, as shown in Table B, positive and negative transverse (+ and $-G_x$) inertial responses are opposite from those occurring under conditions of acceleration.

The present state of knowledge related to voluntary human impact levels is based almost entirely upon studies of young healthy male military subjects under rigid, carefully conducted, and medically monitored conditions. Caution must be used in extrapolating the human test data. Because impact tests on human male volunteer subjects can only be conducted at relatively low noninjurious levels, a number of other test methods have been employed to establish levels considered dangerous to life. Often such tests are reinforced by accidental fall data or other unusual survivals.

Other studies, primarily in the biomechanical disciplines, have focused on regional body tolerances, i.e., concentrating efforts on determining effects of impact forces localized upon a particular body region.

Impact of the restrained or the unrestrained (as in a free-fall situation) individual generally involves whole-body impact. Results of most restraint system studies are thus considered as being whole-body tolerance studies. Such tolerances have been found to differ markedly due to a number of factors, including body orientation and type of restraint system. Data from the literature should be checked to insure that tolerance information from a healthy male subject protected by a sophisticated restraint system is not extrapolated and used to predict the protection provided a subject wearing only a loose lap belt in a side-facing impact.

The literature on restraint systems and tolerance tests of subjects is extensive, and only a brief summary of overall results will be given here. For more detailed test data, original references should be consulted. The most authoritative paper on human voluntary impact tests is by Stapp.[14] For other current test data, requirements, and evaluation of restraint systems, refer to Snyder,[11,18,19] Armstrong and Waters,[20] and Patrick and Grime.[21]

Forward-Facing Seated Positions

Protected only by a lap-belt restraint, human subjects have been voluntarily tested to 26G. In a series of tests, Lewis and Stapp[22] concluded that minimum contusions would result when decelerative force exceeded 10G at 300G/sec rate of onset for 0.002 sec duration. By 13G at the same onset rate and time duration, soreness and muscle strain would be expected. At the highest level studied (26G at 850G/sec for 0.02 sec), no lasting injury was reported although the subject complained of severe epigastric pain lasting for 30 sec after impact and thoracic back strain for two days. In this case, a 3-inch nylon military lap belt was used, impingement pressure was calculated to be 89.5 psi, and belt loads were measured at 4290 pounds. Values up to 15G at these time durations and onset rates have subsequently been considered safe for human acceleration experiments.

For the forward-facing position with lap-belt restraint only, Stapp[14] concluded that "rates of onset between 250 and 1600G/sec and 11.4 to 32.0 peak G can be sustained against a lap belt restraint up to approximately 90 psi average pressure load, with no significant injuries resulting". Effects of higher loads have been investigated with animal subjects. In tests where the lap belt was purposely positioned high and loose, a 30G peak impact value (74.2 ft/sec entrance velocity, 3000G/sec onset rate, 20-deg seat pan pitch, 0.055-sec plateau time, and 0.094-sec total impact duration) produced no significant injury.[19] It has been found that seated human occupants

restrained only by a 3-inch-wide lap belt can survive a peak deceleration of 30G at rates of onset below 1500G/sec with only minor reversible injurious effects. When the G value is increased to more than 38G at 1300G/sec rate of onset, the immediate effects of deceleration are greater than at 45G peak at 500G/sec.

However, as has been pointed out by Swearingen, et al.,[23] if the arching trajectory as the body goes forward to the limits of the lap belt and then jackknifes over the lap belt is sufficiently great, and if the torso is not restrained, the lap-belted occupant will almost certainly strike the forward structure (instrument panel, control yoke, windshield, and other surfaces). Even though whole-body loads of 30G deceleration are survivable with no more than minor injury, fatal injuries at far lower levels can result from the head striking the sharp forward structure. Thus, upper torso body restraint is necessary for effective crash protection of the seated forward-facing aircraft occupant.

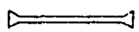
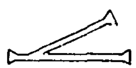
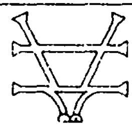
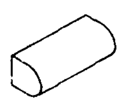
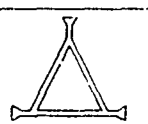
Use of upper torso restraint increases whole-body human tolerance limits to approximately 50G peak (at 500G/sec rate of onset for 0.25 sec duration).[24] Changes in the rate of onset directly affect human response for various impulse durations.[12] Voluntary exposure to peak acceleration of approximately 45G over 0.09 sec at 500G/sec resulted in no sign of shock; yet 38G for 0.16 sec above 1300G/sec produced signs of severe shock,[24,14] and 45G for 0.23 sec at 413G/sec produced severe delayed effects (test run 215 in Reference 24). Air Force design recommendations are 45G for a duration of 0.1 sec or 25G for a duration of 0.2 sec.[25] Restraint in the experiments establishing these limits was provided by a 3-inch-wide double shoulder harness, a seat belt with thigh straps, and a chest belt. Even greater tolerance has been demonstrated in tests with more complete restraint.

Chimpanzee tests corroborate findings from human free-falls that forward-facing, whole-body tolerance with optimum full-body restraint may be about 237G (at 11,250G/sec for 0.35 sec) and about 247G (at 16,800G/sec for 0.35 sec).[13] Persistent injury was found above 135G at 5000G/sec for 0.35 sec, although transient injury effects were observed at 60G at greater than 5000G/sec.[26] It is clear that there is considerable range between the region of human volunteer exposure tested and the known region of injury (Table II).

Rearward-Facing Seated Positions

Rearward-facing ($+G_x$) tolerances are considerably higher than for either forward- or side-facing positions. This is due

TABLE II. HUMAN TOLERANCES FOR WHOLE-BODY DECELERATION IN $-G_x$ FORWARD-FACING SEATED BODY ORIENTATION WITH VARIOUS RESTRAINT (HUMAN SUBJECTS COMPRISED OF HEALTHY YOUNG MALES)

Restraint		Force (lb)	Peak (G)	Onset Rate (G/sec)	Time Duration (sec)	Response	Data Source
	Lap belt, 3-inch width, nylon	4290	15 11.4-23.0 32 ~30	300 280-1600 850 ~1500	0.002 0.002 0.002	Subjective pain threshold limit with no significant injury, highest voluntary level tested; transient injury, minor reversible injury	Lewis and Stapp, 1957[22] Stapp, 1970[14] (p. 334) Lewis and Stapp, 1957[22] Stapp, 1970[14]
	Single diagonal upper torso belt and lap belt	1320 ≈ 1800				Voluntary pain threshold Estimated probable threshold injury	Armstrong and Waters, 1969[20] SAE J885a (revised)[10]
	Double shoulder harness and lap belt	 7954	45 45 38 45 45(a) 50	500 1300 413 500	0.090 0.100 0.160 0.200 0.230 0.250	No sign of injury Signs of severe shock (Retinal hemorrhage, severe headache, severe delayed transient effects run No. 215) Estimated limit for non-reversible injury	HIAD[25] HIAD[25] Stapp, 1951; 1970[24,14] Stapp, 1951[24]
	"Optimum" full body restraint; double shoulder harness, 3-inch width, lap belt with thigh straps, plus chest belt		>60 >135 237 247	5000 5000 11250 16800	0.350 0.350 0.350 0.350	"Transient" injury effects (b) "Persistent" injury effects (b) Nonreversible injury tolerance (b) Nonreversible injury tolerance (b)	Stapp, 1958[26] Stapp, 1958[26] Stapp, 1961[13] Stapp, 1961[13]
	Passive restraint (webbing, inflatable, self-deploying blanket, net, or other device)	0-375(c) 1200	9 40(d) >57 >123	 5900 5482	 0.002 0.079 0.213	First tests with human volunteers Lung, liver congestion, pulmonary edema considered transient injuries. No significant degree of incapacitation (e)	Gragg, et al, 1970[27] (NHSB Proposed tolerance levels for passive restraints)[28] Snyder, et al, 1967[29] Clarke, et al, 1970[30]
	Inverted Y-Yoke shoulder harness with inertial reel and lap belt (f)		>49	6100	0.073	Nonreversible injury threshold (e)	Snyder, et al, 1967[29]

(a) Sled G; (b) Based upon chimpanzee tests; (c) Rebound (peak force), lap belt, and air bag; (d) Resultant; (e) Based upon baboon tests; (f) Based upon baboon tests, and three auto accidents with no reported injuries for restrained occupants in estimated ~70-mph impacts.

primarily to the greater distribution of loading throughout the entire back area of the seated occupant. While human tolerance in a rearward-facing body orientation has not been clearly established, the occupant so positioned can be expected to withstand 30G for 0.11 sec duration when the calculated rate of onset is 1065G/sec.[31] Forty G peaks at 2000G/sec rate of onset will cause severe but transient responses.[14] A level of 83G (chest acceleration) at 3800G/sec for 0.04 sec duration has been tolerated with only transient injuries reported.[32] The current Air Force design limit falls between this and 45G for 0.1 sec[25] (Table III).

TABLE III. HUMAN TOLERANCES FOR WHOLE-BODY DECELERATION IN $+G_x$ REARWARD-FACING BODY ORIENTATION

Peak G	Onset Rate (G/sec)	Time Duration (sec)	Response	Data Source
30	1065	0.110	No injury	Stapp, 1949[31]
40	2000		Severe but transient response	Stapp, 1949[31]
82.6 (chest) 40.4 (sled)	3800	0.040	Highest voluntary measured test, transient injury	Beeding, et al.[32]
>45		0.100	Estimated injury threshold Air Force design limit	HIAD[25]

Side-Facing Seated Positions

Knowledge of human response to lateral deceleration forces ($\pm G_y$) is very limited, but tests to date strongly indicate that tolerances are lower for this position than for either forward- or rearward-facing body orientations. Human subjects have found the subjective pain threshold to be 9G (average) for a duration of approximately 0.1 sec.[33,34] (Use of the word subjective in this discussion refers to deceleration levels that human subjects would not voluntarily submit themselves to.) Even when body restraint consisting of both lap belt and upper torso harness is worn, Sonntag[35] found the maximum voluntary subjective tolerance to be 14.1 peak sled G at 600G/sec rate of onset for 0.122 sec duration.

More recent tests with the F-111 restraint system (General Dynamics' version) resulted in subjective tolerance levels of 12 to 14G measured on the chest.[35] Other data developed in the space program[36,37] and from free falls into water[38,39] indicate that human tolerance to lateral forces remains considerably below that of human tolerance to forces experienced while seated in the forward- or rearward-facing positions. Lateral body orientation impact studies have been conducted with animals to a limited degree. Rhesus monkeys have been exposed to 75G peak.[40] A black bear attired in full Apollo restraint system less helmet survived a 46G peak (velocity change of 32 ft/sec and 4180G/sec onset rate) without reported injury;[41] five chimpanzees decelerated on the Holloman rocket track survived 20.8 to 47.0 (calculated) $+G_y$ at 929 to 1180G/sec rate of onset for 0.118 to 0.17 sec duration;[42,43] and guinea pigs have been exposed to 240G (0.033 sec at 200,000G/sec rate of onset) in the fully contoured isovolumetric support system.[44] However, lateral tests of baboons restraind only by a lap belt have been found to produce fatal pancreatic injury at levels as low as 16.5G.[19]

Lateral tolerance data is summarized in Table IV.

TABLE IV. HUMAN TOLERANCES FOR WHOLE-BODY DECELERATION IN $\pm G_y$ LATERAL BODY ORIENTATION

Restraint	Peak G	Onset Rate (G/sec)	Time Duration (sec)	Response	Data Source
Lap belt	9 (average)		0.100	Subjective pain threshold	Zaborowski, 1966; Zaborowski, et al, 1965[33,34]
Lap belt	14.1	600	0.122	Maximum voluntary pain level	Sonntag, 1968[35]
3-inch double shoulder belt plus 3-inch lap belt	10		0.060	Voluntary pain threshold	Zaborowski, et al, 1965[34]
3-inch lap belt plus 30-degree side limiting	12		0.100	Subjective transitory injury threshold	Zaborowski, 1966[33]
(Values below for information only. Probably not applicable to light aircraft.)					
F-111 restraint	14.0 (chest) 10.0 (sled)	215			Reader, 1967[14]
Mercury full body	>21.5 (sled)	1190	0.121	Subjective voluntary level	Weis, et al, 1963[36]
Apollo	18.7 (sled)			No complaint	Brown, et al, 1966[37]
Apollo	>47	1180	0.170	(Chimpanzee) survival	Stapp, 1952; Stapp, 1955[42,43]

Head Impact Tolerance

In aircraft accidents, impact to the head has been found to be the single most frequent cause of injury as well as the primary cause of death. Seventy-five percent of aircraft crash fatalities may be attributed to head injury. Such trauma occurs through head contact with structure or projections rather than as the action of acceleration forces on the head as a whole.

Probably no region of the body has received more investigation of the effects of impact stress than the head. The effects of skull fracture, cervical injury, and the mechanisms of concussion and brain injury have been studied in these investigations. During 1969, the effects of mechanical forces on the skull, scalp, or brain tissues received the attention of 284 investigators working on 92 different research projects in this country alone.

Several sensitivity curves have been developed in attempts to predict injury through isolation of parameters of magnitude, duration, and onset rate. Of varied usage are the Wayne curve,[45] the J-tolerance value,[46] the Michigan curve,[47] the Brinn[48] effective displacement index (EDI), and the Gadd severity index.[49] For comparison with the sensitivity curves, particular values of skull failure loads are tabulated in Tables V and VI.

TABLE V. LOCALIZED SKULL BONE PENETRATION VALUES FOR DYNAMIC IMPACTS FROM PROJECTIONS WITH AN EFFECTIVE CONTACT AREA OF ~ 1 SQUARE INCH AND LESS

Penetrator Contact Surface	Peak (G)	Average Failure Load (lb) (Frontal Impact $-G_x$) Frontal Bone	Average Failure Load (lb) (Side Impact $+G_y$) Parietal Bone	Minimum Failure Loads (lb) (Frontal Impact $-G_x$) Frontal Bone	Minimum Failure Loads (lb) (Side Impact $+G_y$) Parietal Bone	Data Source
0.313 inch cylindrical shape (5/16 inch)		1230	-	700	-	Hodgson, et al, 1970[50]
0.432 inch flat (7/16 inch)		1030	780	500	140	Melvin, et al, 1969; 1970[51,52]
0.500 inch "cookie-cutter" rim (1/2 inch)		1480	880	1000	400	Melvin, et al, 1969; 1970[51,52]
0.612 inch flat (≈ 5/8 inch)		1710	1290	1000	500	Melvin, et al, 1969; 1970[51,52]
0.670 inch flat (3/4 inch)		1000	770	620	400	Messerer, 1880[53]
1.000 inch cylindrical shape (1 inch)		1260	-	950	-	Hodgson, et al, 1970[50]
1.000 inch flat (1 inch)	80					Swearingen, 1965[54]
1.130 inch flat, padded (1-1/8 inch)		1225 1100, 10 msec	790	900	450	Nahum, et al, 1968[55]

With decreasing contact surface area, the probability of penetration (and injury to the impacted occupant) at lower energies increases steeply. This is not apparent in the above comparison simply because energy is not considered in this table.

TABLE VI. FOREHEAD (FRONTAL BONE) INJURY TOLERANCES FOR $-G_x$ FRONTAL IMPACT WHERE AREA OF CONTACT IS GREATER THAN 1 INCH

Contact Surface	Frontal Bone Load (lb)	Time Duration (sec)	Energy (in.-lb)	Peak (G)	Data Source
 2.000 inch cylinder (2 inches)	1000	0.002			Hodgson, et al, 1970[50]
 2.500 inch block, square				190-330	Swearingen, 1965[54]
 2.500 inch flat, padded (2-1/2 inches)	2000	0.004			Hodgson, 1967[56]
 4.000 inch flat				150	Swearingen, 1965[54]
 6.000 inch flat (6 inches)	400*	0.005			Patrick, 1971[10]
 6.000 inch flat, padded (6 inches)	285*	0.032	400-900 (600 average)		Patrick, 1971[10] Gurdjian, et al, 1949[57]
Motor vehicle instrumentation panel or seat back		0.003		70 90 (max. resultant)	NHSB, Amendment FMVSS 208, 1970

*Human volunteer pain threshold.

The Wayne curve indicates the relationship between acceleration and time required to produce moderate concussion from human forehead impact on a flat hard surface. Tolerance to 180G for 2 msec, 135G for 3 msec, 110G for 4 msec, 80G for 8 msec, 74G for 10 msec, and 57G for 20 msec was observed. A previous Wayne curve indicated the relationship between acceleration and time required to produce fracture.

A widely used head impact tolerance scale is the Gadd severity index (SI),[49] which consists of a weighted impulse criterion used to assess the degree of head injury potential of a force or acceleration pulse. This impulse-integration process is an attempt to relate the importance of time and intensity of the pulse rather than a measure of peak G or impulse area. A value of 1000 indicates that the threshold of danger to life from internal head injury due to frontal blows has been reached.

A linear impact tolerance curve has been computed based on driving point mechanical impedance techniques with maximum strain as the criterion for injury. This Michigan curve,[47] still under development, is shown in Figure 2. These predictive curves are discussed in Reference 11 and in several papers of the Fourteenth Stapp Car Crash Conference.[48,49] Insufficient data are available, to date, to predict injury levels for impacts to the side of the head.

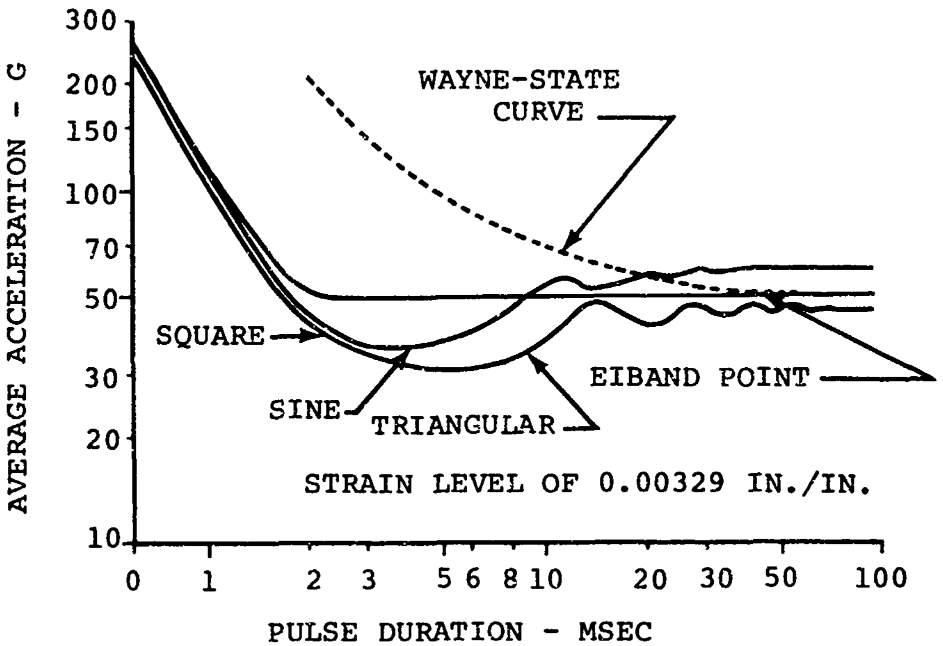


Figure 2. Human Head Injury Tolerance Curves Indicated by Maximum Strain for Frontal ($-G_x$) Impact Developed by Stalnaker and McElhaney.[58,59]

Chest Impact Tolerance

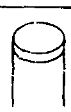
Although injury to the chest is not as frequent as injury to the head and upper and lower extremities, it may be serious when it occurs. The thoracic cage can be penetrated when the control column breaks off on impact.[60] Compression of the chest may also cause injury. Recent thoracic force-deflection studies on primates indicate that chest depth may be compressed as much as two-thirds at moderate impact loads.[61]

Roberts,[62] in experimental impact tests, found that mechanical factors produced displacement of the heart into the left chest, resulting in tears of the aorta and great vessels. Other investigators, such as Laskey,[63] report that biomechanical effects of impact to the cardiovascular system may be caused by shearing of the great vessels, by direct compression of the walls of the heart with bruising and direct tissue injury, or by pressure-volume changes of the blood in closed systems.

The liver and lungs are particularly vulnerable to blunt impact, and pulmonary hematomas or lacerations of the liver are common clinical findings in accidents. In chest compression, ribs may fracture leaving sharp ends which can penetrate the thoracic organs. Some biomechanical studies, therefore, have been directed at chest impact, with particular emphasis on rib fracture. Patrick, et al.,[64] impacted cadaver chests with various surface areas covered with 1 inch of ensolite padding. As a result of these tests, a wheel hub at least 6 inches in diameter with a 4-inch absolute minimum and hub edges rolled to prevent dangerous load concentrations was recommended. Fracture occurred in these localized loadings at 900 to 1000 pounds.[60,65] For impacts to the sternum, shoulder girdle, and abdomen, tolerance was reported to be 1800 pounds.[64] Human voluntary tolerance is about one-third these values.[66] Proposed safety standards for inflatable restraints[28] would limit force on the chest to 1200 pounds, pressure not to exceed 50 psi, and the resultant chest deceleration not to exceed 40G for 2 msec time duration.

At present, these limited criteria represent the best available information for thoracic impact tolerance limits. Tests indicate that tolerance may be increased by distributing any impact loading over as large an area as possible, by attenuating the load through energy-absorbing materials to reduce the initial spike of the acceleration pulse, and by minimizing onset rate and influencing the time duration of input. Mechanisms of blunt body injury to the thorax and abdomen are discussed in detail by Martin[67] and Frey.[68] Chest tolerances are summarized in Table VII.

TABLE VII. HUMAN TOLERANCE FOR THORACIC IMPACT

Contact Surface		Load (lb)	Peak (G)	Time Duration (sec)	Data Source
 Upper Thorax	6-inch diameter, flat, padded	1200			Patrick, et al, 1965[69]
			40 (resultant)	0.002	NHSB FMVSS No. 208, S.53, 1970

Spinal Impact Tolerance

The vertebrae of the lumbar spine receive injury in aircraft accidents much more frequently than the abdominal, thoracic, and cervical vertebrae. In fact, De Haven[70] found such injuries to be more than double those for the cervical spine and thoracic spine grouped together. The comparative rarity of cervical injury in aircraft accidents is in contrast to automobile accidents where whiplash or hyperflexion-hyperextension type cervical injuries are common. Many of the lumbar fractures can be explained by the fact that aircraft crashes often impose a high downward ($+G_z$) load on the occupant's spinal column, and that tolerance for such loads decreases when the individual is thrown forward so that the spine is not aligned. A large number of both biomechanical and medical studies have considered vertebral fractures which remain a major problem in ejection from military aircraft.[71,72] In general, a peak of 20 to 21G for a duration of less than 0.1 sec at a rate of onset of 250 to 300G/sec is tolerable if the spine is properly positioned.

Abdominal Tolerance to Blunt Impact

Since the aircraft accident victim is normally wearing a lap belt on impact, he is usually well protected in the abdominal area from the flailing type injuries other regions of the body may be subjected to. De Haven[70] found in a study of 800 crash survivors of light aircraft accidents that 18.5 percent received abdominal injuries ranging from trivial to severe. Only 2.8 percent of these individuals received abdominal injuries considered to be dangerous to life. Evidence clearly establishes that use of the lap-belt restraint has played a major part in protecting the abdomen from injurious contact in crash decelerations.

While abdominal injuries have been shown to occur with the least frequency of any body region, such injuries can be potentially serious or fatal. Often this may be as a consequence of the problems of clinically diagnosing the specific nature of the internal injury, with delay of treatment (rather than the injury itself) playing a major part in a subsequent fatality. Experimental studies have shown that many injuries occur which would not be diagnosed or discovered without exploratory surgery.

The results of studies conducted for the effect of the direct blunt impact against the abdomen are summarized in Table VIII.

Lap-belt restraint systems, when used properly, fit across the iliac crests of the individual's bony pelvic structure so that

TABLE VIII. HUMAN TOLERANCE FOR ABDOMINAL IMPACT						
Test Condition	Load (lb)	Velocity (ft/sec)	Peak (G)	Time Duration (sec)	Response	Data Source
Edwards AFB sled, impacted against block	2365 5080	23.6 39.6	30 80		Fatal to hog subject Fatal to hog subject	Windquist, et al, 1953[73]
3-inch abdominal belt	750 4700	19.3 44.2			Injured hog subject; survived Fatal to hog subject	
Hyge sled, 3-inch belt, impacted steering wheel rim	410 to 950 (abdomen)	30.0	30	0.063 0.068	Fatal to five hog subjects	Snyder and Young, 1966[74]
Hyge sled, 3-inch belt, impacted steering wheel rim	2020 to 6560 (belt) 3060 (belt)		30	0.074 0.077	Reversible injury to chimpanzee subject	

normally lower abdominal impingement in impact with the belt restraint does not produce injury. New experimental restraints such as the air bag, blanket, or net systems are being developed[75,76,77] to meet proposed NHTSA standards for future passive restraints.[28] Such restraints would automatically restrain the seated occupant in case of impact. The inflatable restraint, in particular, shows promise of providing increased protection, since animal subjects have been tested to 125G levels with this restraint without reaching injury thresholds.[27,29,30] Aircraft installation would pose unique problems of evacuation and installation. Problems yet to be solved include side impact protection and multiple impact protection. Since inflatable restraint systems are activated and exhausted in about 40 msec, they may be effective only when the lap belt is also worn.[30]

PRESENT RESTRAINT SYSTEMS

Forward-Facing, Nonejection Crew Seat

The most common restraint system used by the armed services for forward-facing, nonejection seats consists of a lap belt made from 3-inch-wide polyester webbing, Type IV per MIL-W-25361, and a shoulder harness made from 1-23/32-inch-wide nylon webbing, Type VIII per MIL-W-4088. The lap belt is designated MD-2 and is fully defined by Military Standard 22033. There are two different types of shoulder harness: Y-type, designated MB-2A and defined by Military Standard 16069; and V-type, designated MB-6 and defined by Military Standard 16068. The shoulder harness is connected to the strap of an inertia reel. If it is convenient for the inertia reel to be placed toward the top of the seat back, the MB-6 shoulder harness is

used. If the inertia reel is conveniently placed toward the bottom (closer to the cockpit floor) on the back of the seat back, then the MB-2A shoulder harness is used. No lap-belt tie-down strap (crotch strap) is used with this restraint system.

A lap belt similar to the MD-2, except that the buckle is made to fit a 1-3/4-inch-wide webbing, is the only restraint provided passengers. Figure 3 shows different available varieties of the basic system described above with the associated connecting and attachment hardware.

A seat restraint system has been under development for some time for use in the cockpit of the F-111 aircraft, and the newer F-111E aircraft are equipped with the latest versions of this system. The system uses a lap-belt tie-down strap as shown in Figure 4.

The cockpit of the F-111 aircraft is ejected with both the pilot and copilot canopy and instrument panel. Air bags are inflated under the canopy soon after ejection to reduce the shock of landing. Parachutes help reduce the capsule rate of descent.

Older F-111 aircraft used a different restraint system with three release points and a light polyester webbing (see Figure 5). A retrofit program to replace the older systems with the newer and more efficient system utilizing 1-3/4-inch-wide nylon webbing is planned. The components of this system are made in England and assembled in the USA. The system has been tested on the Daisy decelerator at Holloman Air Force Base. The results of these tests are presented in Reference 78.

An intermediate version, between the old three-point release restraint system and the latest single-point system, had two additional straps (see Figure 6), one on each side of the occupant, attached to the seat at approximately shoulder level and to the lap-belt buckle fitting. However, tests showed[79] that these straps did not carry significant lateral load and they were eventually eliminated.

The Navy has fit-tested the latest versions of the F-111 aircrew restraint system by having a number of people wear it and then critique it. Based on these comments, the Navy feels that the reflected shoulder straps provide very good lateral restraint and that, in general, it is a very good restraint system. The lap-belt tie-down strap (crotch strap) has caused little concern by either the Air Force personnel using the system or the Navy people testing it. It is felt that the lap-belt tie-down strap is needed to prevent submarining.

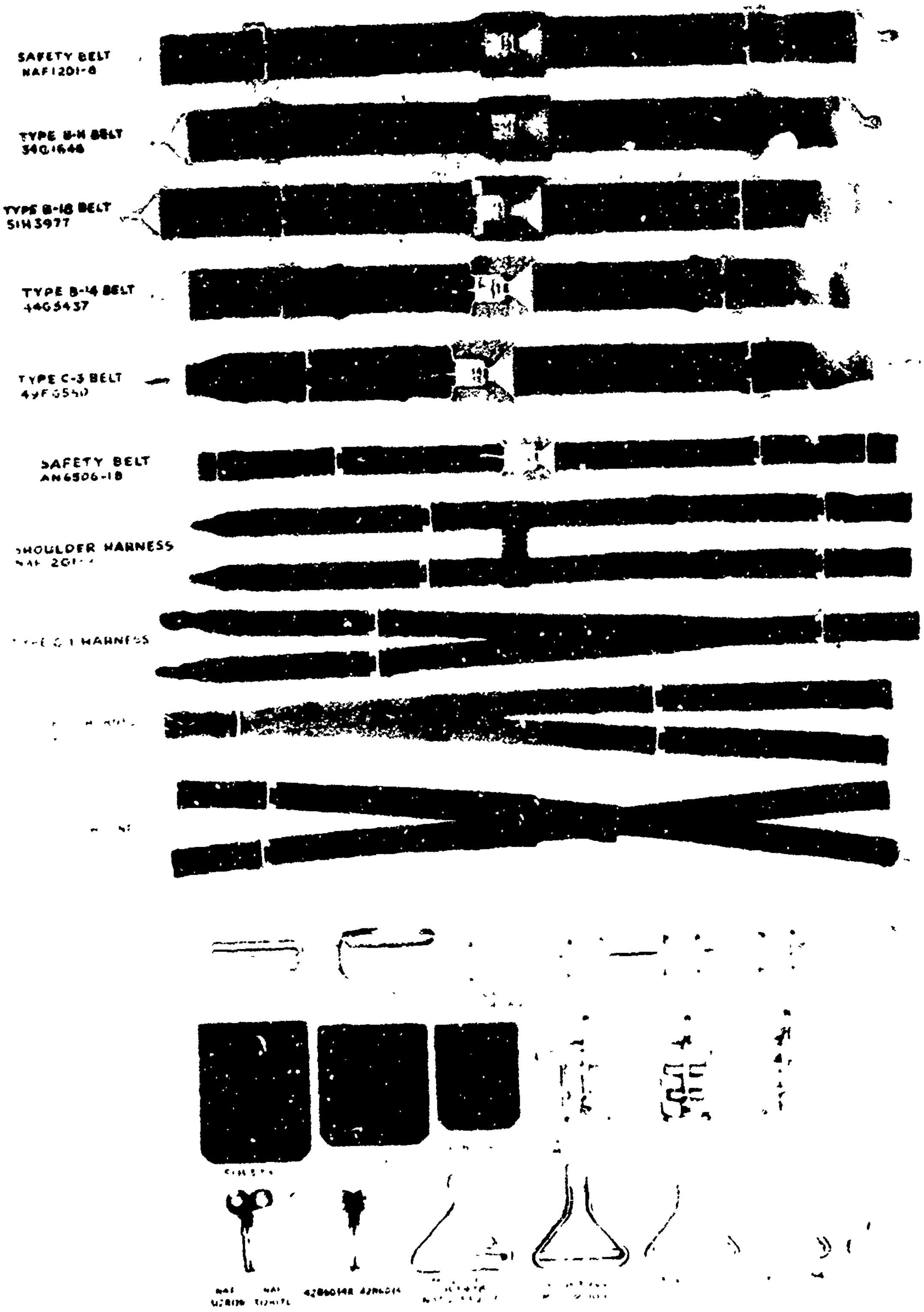


Figure 3. Existing Harnesses and Attachments.

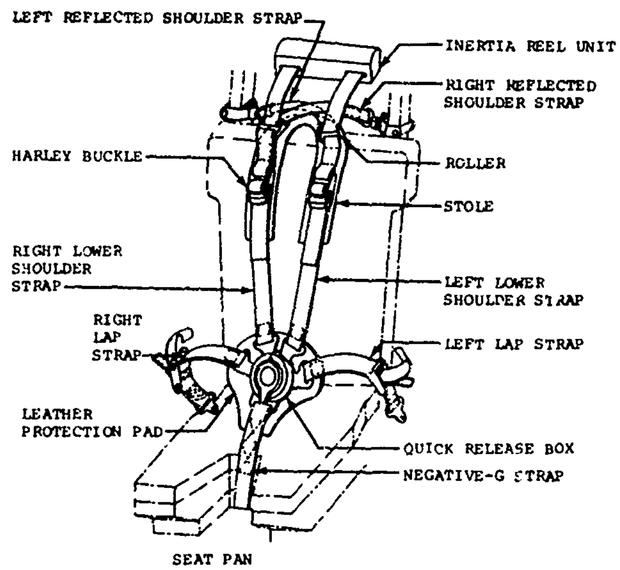


Figure 4. RAF IAM F-111 Harness Restraint System (Latest Version).

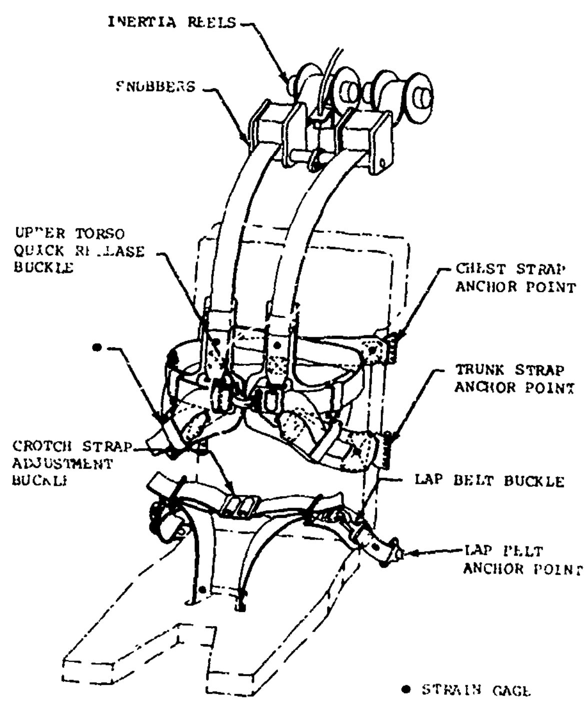


Figure 5. USAF F-111 Harness Restraint System.

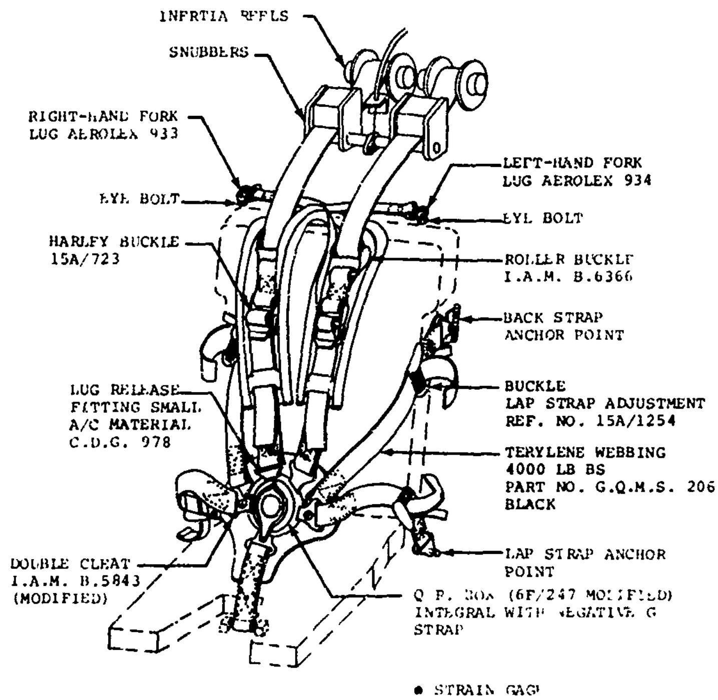


Figure 6. RAF IAM F-111 Harness Restraint System, Stage 2.

Figure 7 shows a typical aircrew restraint system for commercial passenger aircraft, private aircraft, and helicopters that is commercially available in the USA. The system consists of a rotary release buckle, a lap belt, and a shoulder harness. The webbing is Type XXIV nylon per MIL-W-4088. Variations of the lap-belt assembly include versions made from Type VI webbing per MIL-W-4088 with a nominal width of 1-3/4 inches and others made from Type IV webbing per MIL-T-5088 with a nominal width of 2 inches. Variations in the design of the shoulder harness also exist. These include the V- and Y-type configurations for use with a single-strap inertia reel as well as the type shown in Figure 7 which has a double-strap inertia reel.

Another restraint system for private aircraft uses a lap belt made from nylon webbing material, Type XXIV per MIL-W-4088, and a diagonal strap also made from nylon webbing material and attached to an inertia reel. The lap-belt buckle is of the lift-leaf type.

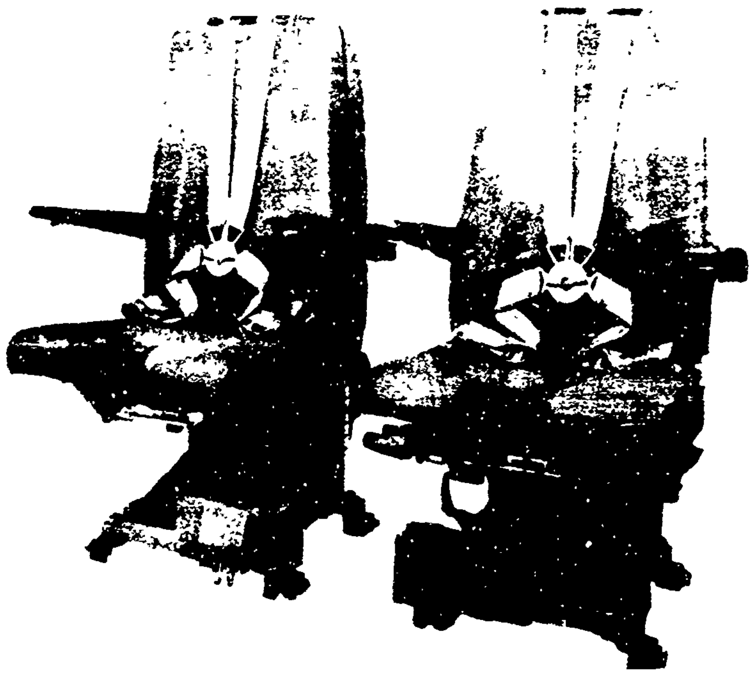


Figure 7. Boeing 747 Captain and First Officer Seats.

Restraint for passengers in commercial aircraft is provided by a lap belt only; the most recent innovation is the incorporation of retractors for passenger convenience and comfort.

All these systems comply with the requirements of FAA TSO-C22.

Forward-Facing, Ejection Crew Seat

Older Air Force aircraft are equipped with ejection seats which require the pilot to put on his parachute before he gets into the aircraft. These restraint systems use the Y- or V-type shoulder harness but incorporate changes to the lap belt and the buckle. The lap belt has two designations, depending on the length. Designation MA-5 is for the lap belt with an overall length of 40 inches, while MA-6 is for the lap belt with an overall length of 54 inches, both at maximum adjustment. The buckle is the same as for the MD-2 except that it has an automatic feature, a gas-operated mechanism that releases the buckle, whereas in the MD-2 the buckle is released manually. The MA-5 and MA-6 lap belts are defined by MS 16036. Again, no lap-belt tie-down strap is used.

In addition to this restraint system, the Air Force, in newer aircraft, provides a quick-fit type harness in one size which can be adjusted to fit the service population. It is basically a parachute harness adapted to provide restraint in the ejection seat that is identified as PCU-3/P.

The Army also currently uses a quick-fit type harness similar in design to that of the Air Force. The latest design of this harness is identified by Part Number ES-186-1 (see Figures 8, 9, and 10). The Army harness was originally designed as a parachute harness. It was modified to adapt to a particular ejection seat to also serve as a restraint harness.

The Navy uses a type MA-2 torso harness suit. This suit is provided in twelve sizes to accommodate the 5th to 95th percentile size range, including all clothing variables and G and antiexposure suits. The type MA-2 torso harness suit was originally designed as a restraint garment for capsule application and later qualified as a parachute harness. During military operations in Southeast Asia, it was reported that wearing of the standard MA-2 torso harness suit by aircrewmen caused thermal discomfort due to high ambient temperature and humidity. Reference 80 describes a test program conducted at the Naval Aerospace Recovery Facility, El Centro, California. The program objectives were to compare strength, structural integrity, thermal comfort, and wearability when using Raschel knit fabric versus nylon cloth for modified MA-2 harness channel and panel areas. It was concluded that the gain in thermal comfort is negligible and does not warrant the introduction of Raschel fabric into the system. It was recommended that the modified MA-2 torso harness with nylon cloth be retained for service use.

A Navy pilot wearing a torso harness suit must make four connections for his restraint system when he gets into the aircraft, two at the shoulder straps and two at the lap belt. The male part of these connections is attached to the torso harness suit while the female parts are attached to the ejection seat. An Army or Air Force pilot wearing a quick-fit type harness has three connections to make, two at the shoulder and one at the lap-belt buckle. None of these systems uses a crotch strap, increasing the possibility of pilot submarining during a crash or seat ejection.

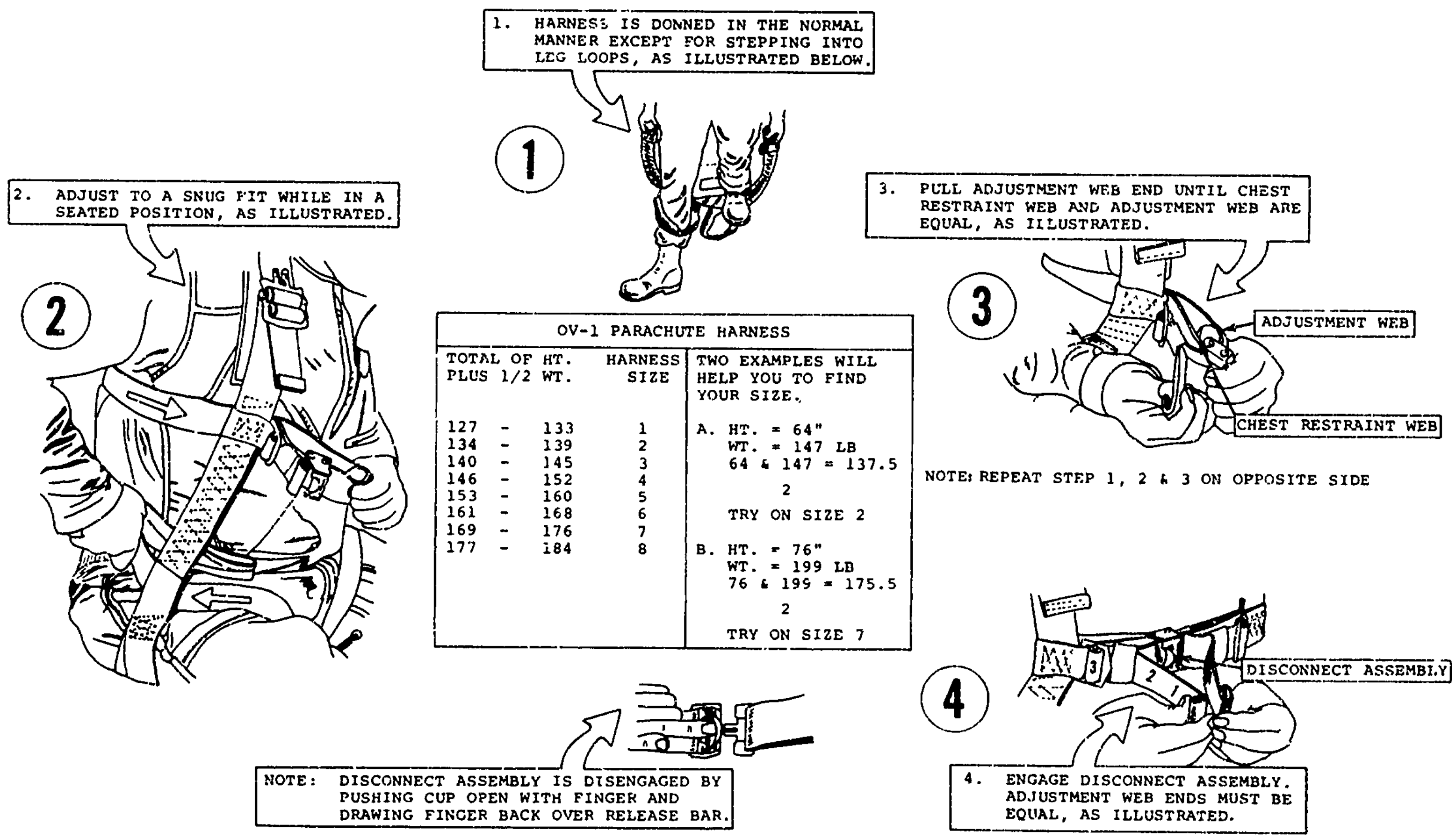
RESTRAINT SYSTEM IMPROVEMENTS

Nonejection Crew Seats

The Navy is investigating single release buckles to replace the latch-type buckle. Also, efforts are under way to change

Figure 8. Front View of Quick-Fit Harness.

Figure 9. Rear View of Quick-Fit Harness.



OV-1 PARACHUTE HARNESS

TOTAL OF HT. PLUS 1/2 WT.	HARNESS SIZE	TWO EXAMPLES WILL HELP YOU TO FIND YOUR SIZE.
127 - 133	1	A. HT. = 64"
134 - 139	2	WT. = 147 LB
140 - 145	3	(64 & 147)/2 = 137.5
146 - 152	4	TRY ON SIZE 2
153 - 160	5	
161 - 168	6	
169 - 176	7	
177 - 184	8	B. HT. = 76"
		WT. = 199 LB
		(76 & 199)/2 = 175.5
		TRY ON SIZE 7

Figure 10. OV-1 Parachute and Ejection Seat Restraint Harness.

the webbing material of both V- and Y-type shoulder harnesses from nylon to polyester. The Navy has developed a ratchet-type tightener to remove lap-belt slack. The ratchet tightener is capable of removing 2 inches of slack from each side of the belt and will be used with the newly designed seat for the Helicopter Escape Personnel Survival (HEPS) program. The restraint system will be a 3-inch-wide lap belt with the 1-3/4-inch-wide shoulder harness, made from polyester webbing material. The lap belt will be equipped with the regular adjusters since the ratchet-type lap-belt tightening capability is limited.

Ejection Crew Seats

All branches of the armed services are currently engaged in work to reduce injuries by improving pilot restraint and positioning during ejection.

The Air Force has awarded a production contract for the HBU-2A/A automatic lap belt (see Figure 11). This lap belt will eventually replace the standard MA-5 and MA-6. A recently developed rotary buckle and a 2-to-1 ratio adjuster are the new items of this lap belt. The buckle can be actuated manually or with compressed gas; hence, the name automatic. The buckle was to fit a 3-inch-wide webbing originally; however, the Air Force changed this requirement to the present 1-3/4-inch-wide webbing.

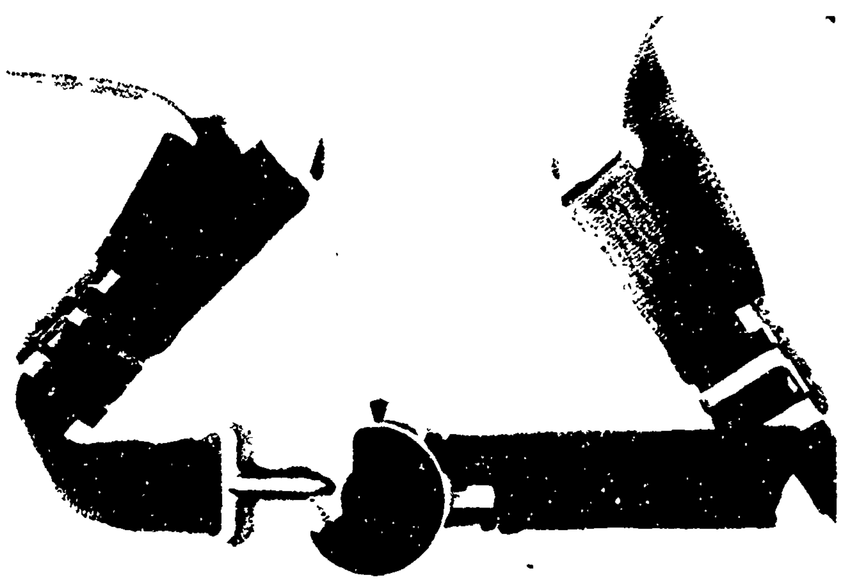


Figure 11. HBU-2A/A Automatic Lap Belt.

The HBU-2A lap belt was first used with the ejection seat developed for the T-37 aircraft. However, due to the significant advantages of the rotary buckle as compared to the latch-type buckle, the HBU-2A/A lap belt was selected to replace the MA-5 and MA-6 in service on ejection seats. The HBU-2A/A lap-belt assembly has a body block ultimate static strength of about 5400 pounds. The buckle is certified for 2000 pounds static tensile load.

In the HBU-2A/A lap-belt assembly, there are two adjusters, two end fittings, and a webbing-to-buckle fitting. The webbing is 1-23/32-inch-wide nylon material, Type XIII per MIL-W-4088, resin treated per MIL-W-27265. The stitch pattern for the lapped joints is a four-point "W-W" with a seam length of 2-3/4 inches, using No. 6 nylon cord per V-T-285. The adjusters were developed for the Air Force and they are certified for a 6000-pound static tensile load. The webbing-to-buckle fitting has an ultimate static tensile strength of 8000 pounds. For quality assurance, each lap belt is tested at the end of the assembly line. A load of 30 pounds is applied on each end of the belt and the locking and release mechanism is checked for performance and ease of operation. At regular intervals (approximately every 200 pieces), the lap-belt assembly is tested in a body block machine. As the load applied to the body block is exerted on the lap belt, a simulated shoulder harness load of 1800 pounds is exerted on the buckle in a manner similar to actual loading. Before the body block load reaches 6000 pounds, the webbing invariably fails at the adjuster (the adjuster cuts the webbing).

Temperature cycling and humidity tests are also performed. Inside the buckle there is a rubber O-ring that fails at -65°F. There are no reliability data available for the buckle. Although there are provisions for a lap-belt tie-down strap on the buckle and the ejection seats, the Air Force does not use a tie-down strap at the present time. As a result, regardless of how tight the adjusters are, the lap belt permits submarining.

The HBU-2A/A lap belt, slightly modified (see Figure 12), has been proposed to the Army and the Canadian Air Force for use in certain seats. Another lap belt, the HBU-4A/A model, is identical to the HBU-2A/A except the parachute lanyard connection is locked out. Model HBU-4A/A is for use with gun deployed parachute systems (F-106, F-105, and F-104) where connection to the lap belt is not required.

Studies conducted by the Air Force and Navy with the Air Force versions of the Army quick-fit parachute/restraint harness revealed deficiencies in relation to occupant restraint during

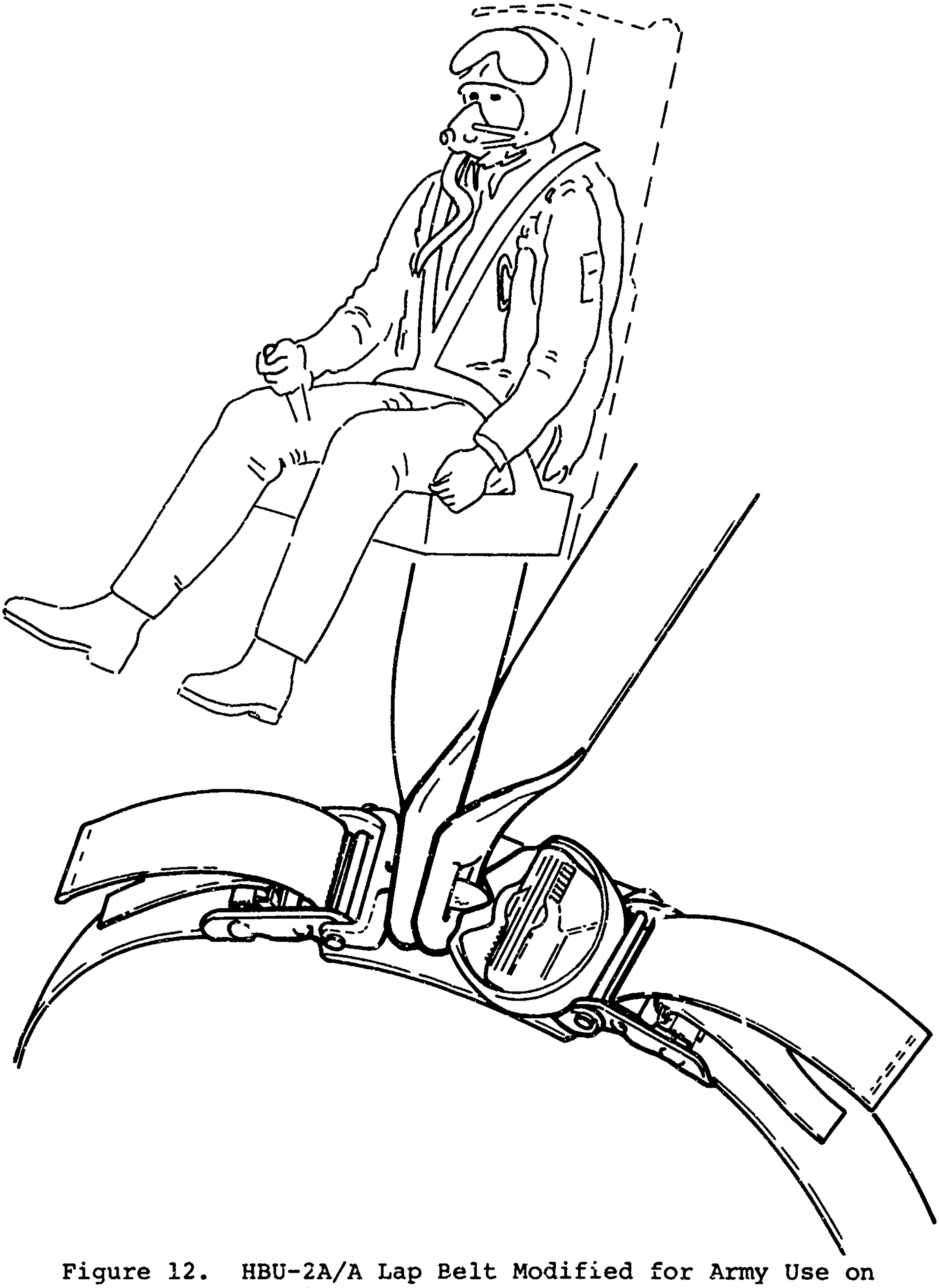


Figure 12. HBU-2A/A Lap Belt Modified for Army Use on Martin-Baker Seats.

ejections. As a result of these tests and a history of vertebral injuries within the three services, it was concluded that the quick-fit harness is undesirable for ejection seat use. During the tests, the Navy torso harness suit parachute/restraint harness showed advantages over the Air Force/Army quick-fit harnesses. Consequently, the U. S. Army Natick Laboratories have designed a torso harness compatible with other improvements undertaken for the OV-1 aircraft escape system. This harness is fixed and is not a quick-fit, fully adjustable harness. The Air Force has also developed a torso harness suit for the majority of the newer aircraft equipped with ejection seats.

The greatest disadvantage of the torso harness suit restraint is the four connections. Reference 81 describes some of the difficulties encountered by pilots wearing the torso-type restraint harness in crash landings, aborted takeoffs, or gear collapse resulting in postcrash fire. The pilot must suddenly make an emergency egress, but the many restraint members that held him secure and unhurt during the sudden stop now work to inhibit his survival. At least 40 aircrew members faced with emergency ground egress situations during 1968 and 1969 experienced difficulty and delay. Not all of these survived.

Realizing that valuable time would be lost in the case of an emergency landing accompanied by ground fire, both the Air Force and the Navy are working on a single-release system for the four connections of the torso harness suit restraint. No other information is available from the Air Force, and information concerning the Navy system is proprietary. The system uses an electronic device which can be manually actuated or automatically actuated by sensing impact (water or ground). The Navy feels that, since it is an electronic device, the reliability of the system can be good.

The Air Force has also developed a single-point release restraint system, not of the torso harness-suit type, for ejection seats (see Figures 13, 14, and 15). This system uses mostly existing parachute-type hardware and 2-inch-wide nylon webbing. The novelty of the system is a newly designed four-point release buckle. The rectangular buckle appears to be big (about 3 by 5 inches) and incorporates a push-lift mechanism. The developer claims that the release mechanism can be worked easily with either hand; however, it appeared from photographs that a left-handed person, even under normal circumstances, might have some difficulty in releasing the buckle. In order to activate the release mechanism, the right half of the buckle (when worn with the restraint system) must be pushed in while the left half must be lifted. This motion is easily executed by the right hand, pushing with the palm and

Figure 13. New Ejection Seat With a Single-Point Release Restraint System.

lifting with the fingers. The process must be reversed when the left hand is used and the fingers must push in while the palm lifts. This might cause some difficulty, especially in an emergency when the occupant is not very familiar with the buckle. When the buckle release mechanism is activated, a quick disconnect in the oxygen supply line to the mask is also disconnected.

The lap-belt tie-down strap function for this system as well as for the torso harness suit is performed by part of the parachute assembly, so the pilots do not see it as a crotch strap and therefore do not object. General comments on the system and interpretation of test results are conflicting. The people directly involved with the development of the system believe that the system and the results of the tests are good, with the exception of the shoulder harness padding which was not resting properly on the shoulders. Others mainly involved

Figure 14. Front View of the Occupant Restrained by the Single-Release Restraint System of a New Ejection Seat.

Figure 15. Three-Quarter View of the Occupant Restrained by the Single-Release Restraint System of a New Ejection Seat.

with the testing are not very enthused. The feeling is that the system is bulky and not very convenient to don and doff. The system has been comparatively tested against the standard 3-inch-wide polyester lap belt and 1-3/4-inch-wide nylon shoulder harness combination as well as the torso-harness suit restraint for the F-4 aircraft; however, the results of the tests have not been available.

ANALYTICAL MODELING

In restraint systems analysis, optimization, and design, the effects of a multitude of variables must be evaluated. Two extremely powerful tools to economically characterize the effects of the variables on system performance and design are available. The first of these tools consists of kinetic modeling. Kinetic models which are mathematical simulations of vehicles, restraint systems, and occupants are programmed on computers for high-speed evaluation of the effects of variables. This tool is used to produce time-related histories of vehicle-occupant response when subjected to dynamic environments characteristic of vehicle crashes.

The second tool is the anthropomorphic dummy or physical model of the human body. Dummies can be positioned in vehicles or simulated vehicles and subjected to chosen input crash conditions. Time histories of the response of these dummies are then obtained in an empirical fashion in much the same form as results from the analytical technique. The accuracy of this information is limited by the difficulty of precise simulation of the human body.

Many kinetic models have been developed in the last few years in the form of computer simulation programs. The complexity of these programs ranges from a simple lump-mass damped-spring model programmed on an analog computer[82] to the three-dimensional program recently being developed under NHTSA Contract FH-11-6962.[83,84]

The three-dimensional models have more degrees of freedom and are thus more costly to use than two-dimensional models. At present, none have been sufficiently verified by comparison with test data to allow a high level of confidence in their results. For these reasons a proven two-dimensional program was chosen for use in the variables analysis. An added advantage was that the program chosen was developed at Dynamic Science and personnel were already familiar with its use.

The simplified model of the seat-passenger system used in the analysis is shown schematically in Figure 16. The seat and passenger are considered to have a plane of symmetry, and all

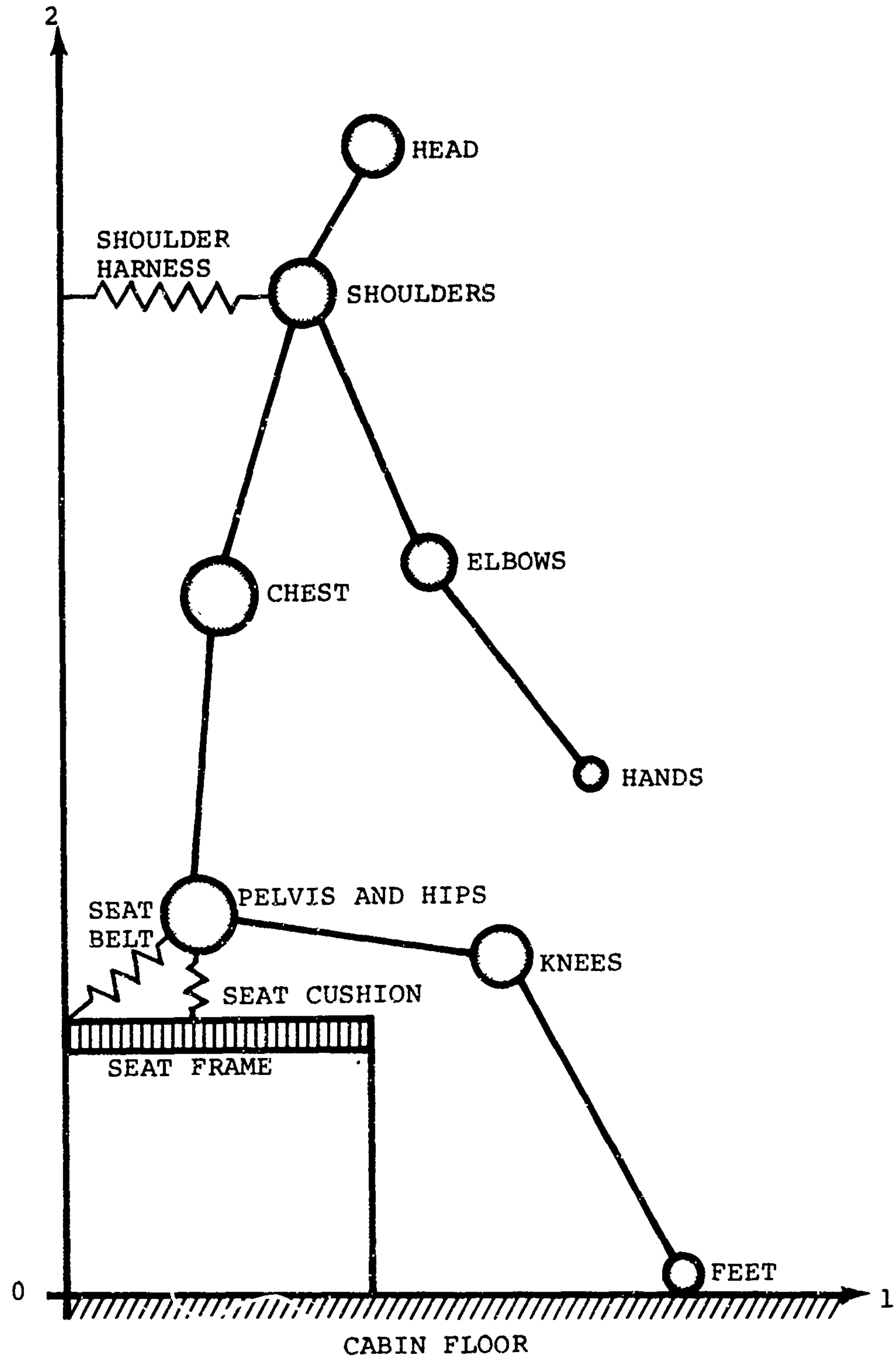


Figure 16. Simplified Model of Occupant and Seat Used in the Mathematical Analysis.

masses and forces are assumed to act in this plane. The forces, positions, displacements, velocities, accelerations, and jerks (time derivatives of accelerations) are given with respect to the x-y coordinate system shown in Figure 17.

The calculation is based on a numerical analysis in which twelve differential equations of motion for the system are expressed in terms of twelve generalized coordinates, their first and second time derivatives, and the forces in the system. The details of these equations, together with the techniques of numerical analysis used in this solution, are presented in Reference 85. The resulting computer program SIMULA and related subprograms and subroutines are listed in Appendix IC of Reference 86. A complete tabulation and interpretation of the input for this program are shown in Appendix IB of Reference 86.

Individual physical system parameters were experimentally verified throughout the 3 years during which the computer program was developed. The final verification involved 4 major acceleration test-sled experiments and corresponding computer runs for 4 widely varying conditions. The results of one such test, MTT-19, are depicted in Figures 18 through 22. For this particular test, a dummy was positioned in a test seat in the sled with seat belt only, in a slightly jackknifed position. The seat was oriented to give a vertical component of acceleration of 27 percent of the horizontal pulse. The horizontal pulse used is shown in Figure 22, depicting both the experimentally measured acceleration-time pulse in the horizontal direction and the computer approximation used in the calculation.

Figures 19 through 22 indicate the comparison between computer calculations and experimental measurements for seat belt load, vertical front and rear leg loads, and horizontal shear load at the floor for test MTT-19. Other tests yielded results similar to these; discrepancies in the worst case ranged from 20 to 30 percent, but for most cases they were less than 20 percent. Comparisons of other system responses, such as seat belt extension and passenger kinematics, also showed very acceptable agreement between computer predictions and experimental measurements.

AVAILABLE HARDWARE

A great number of restraint system hardware components (buckle, adjuster, tie-down attachments, etc.) are available on the market today. Most have been developed for use in commercial and private aircraft and automobiles, with a very limited number for military applications and the space program. Innovative ideas and designs for the development of hardware are

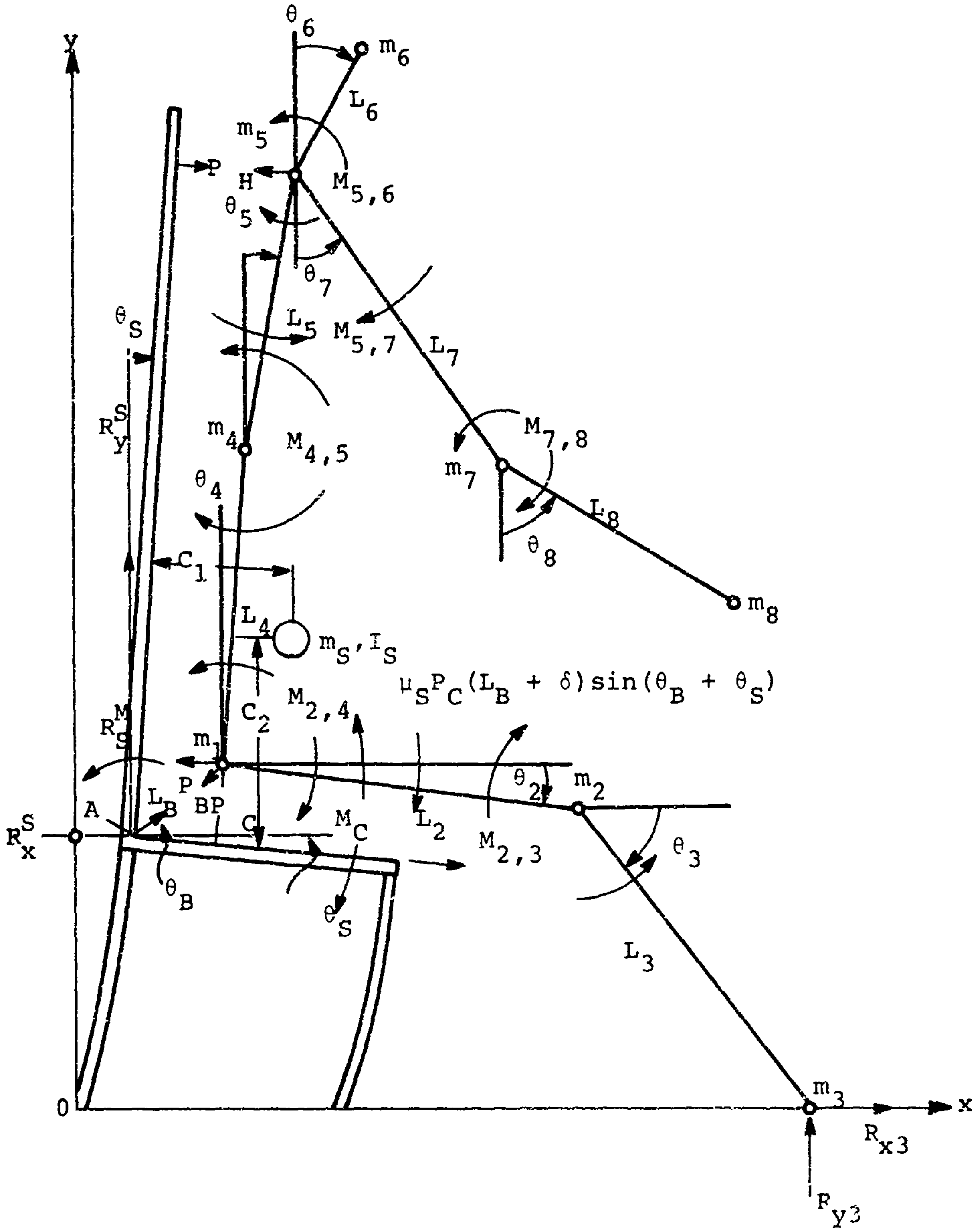


Figure 17. Free-Body Diagram of Occupant and Seat.

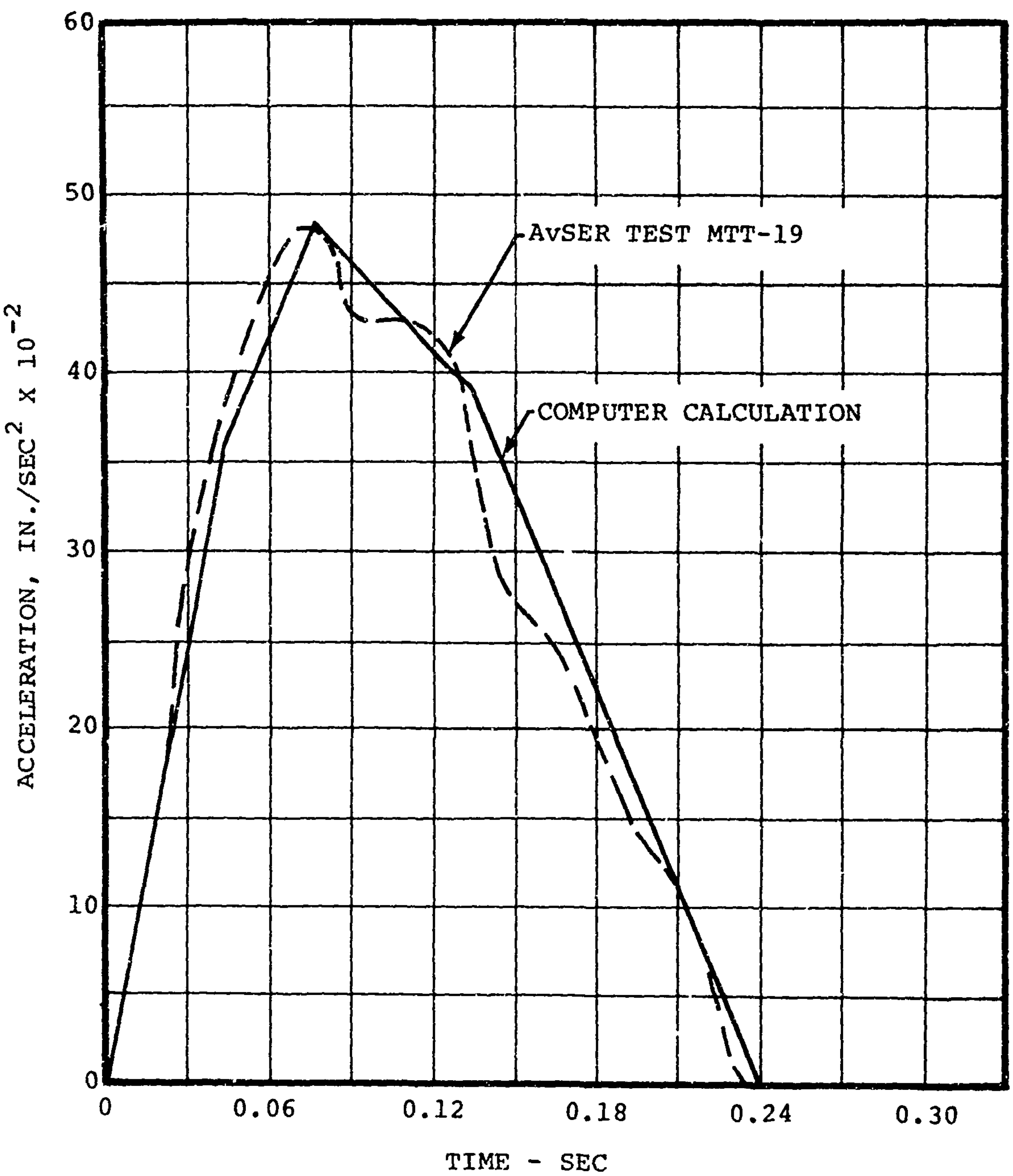


Figure 18. Horizontal Acceleration-Time Pulse Used in the Experiment and in the Computer Calculation Which Resulted in the Data Shown in Figures 19 Through 22.

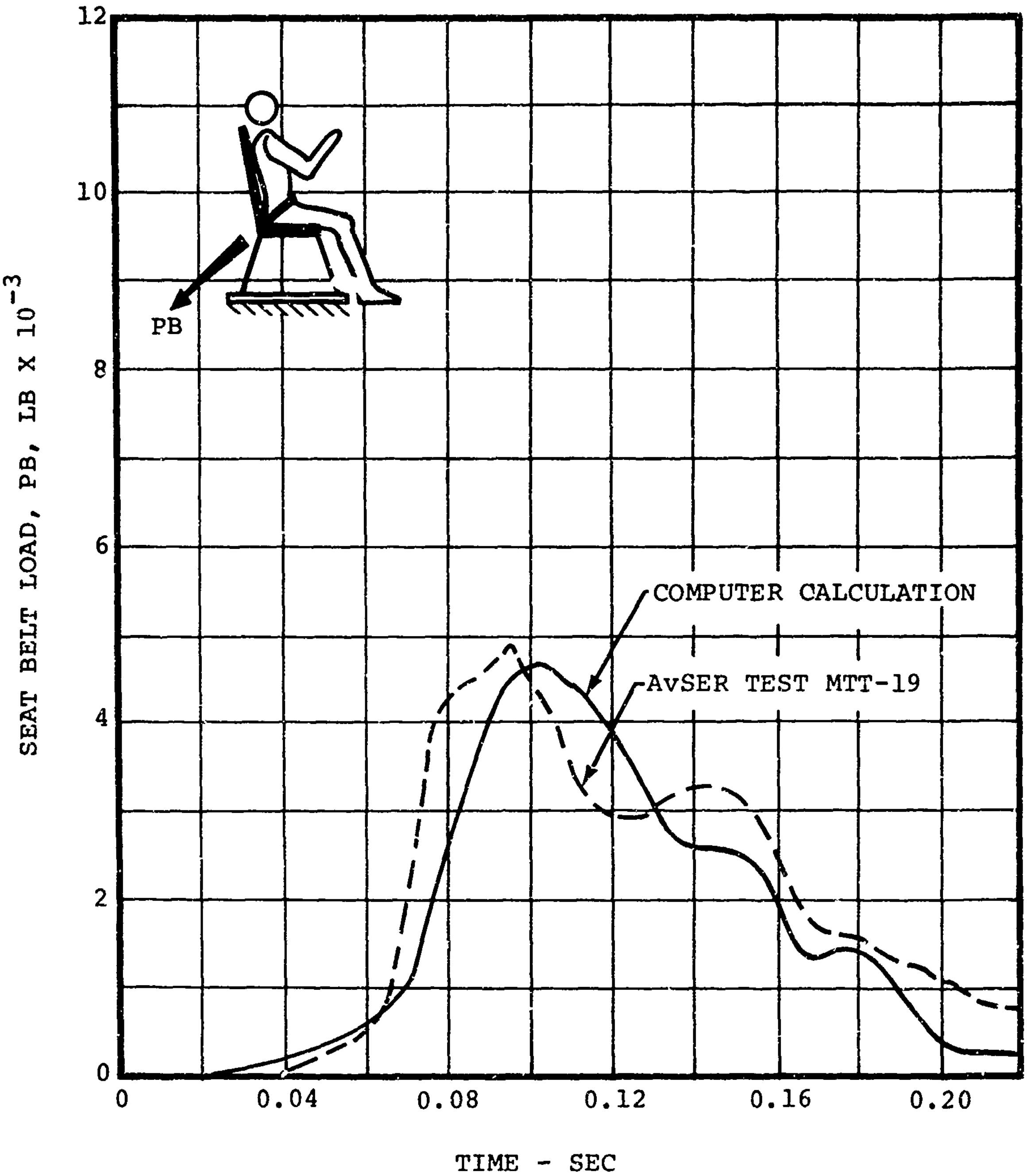


Figure 19. Comparison of Experimental Results With Computer Calculation of Seat Belt Load for Case MTT-19.

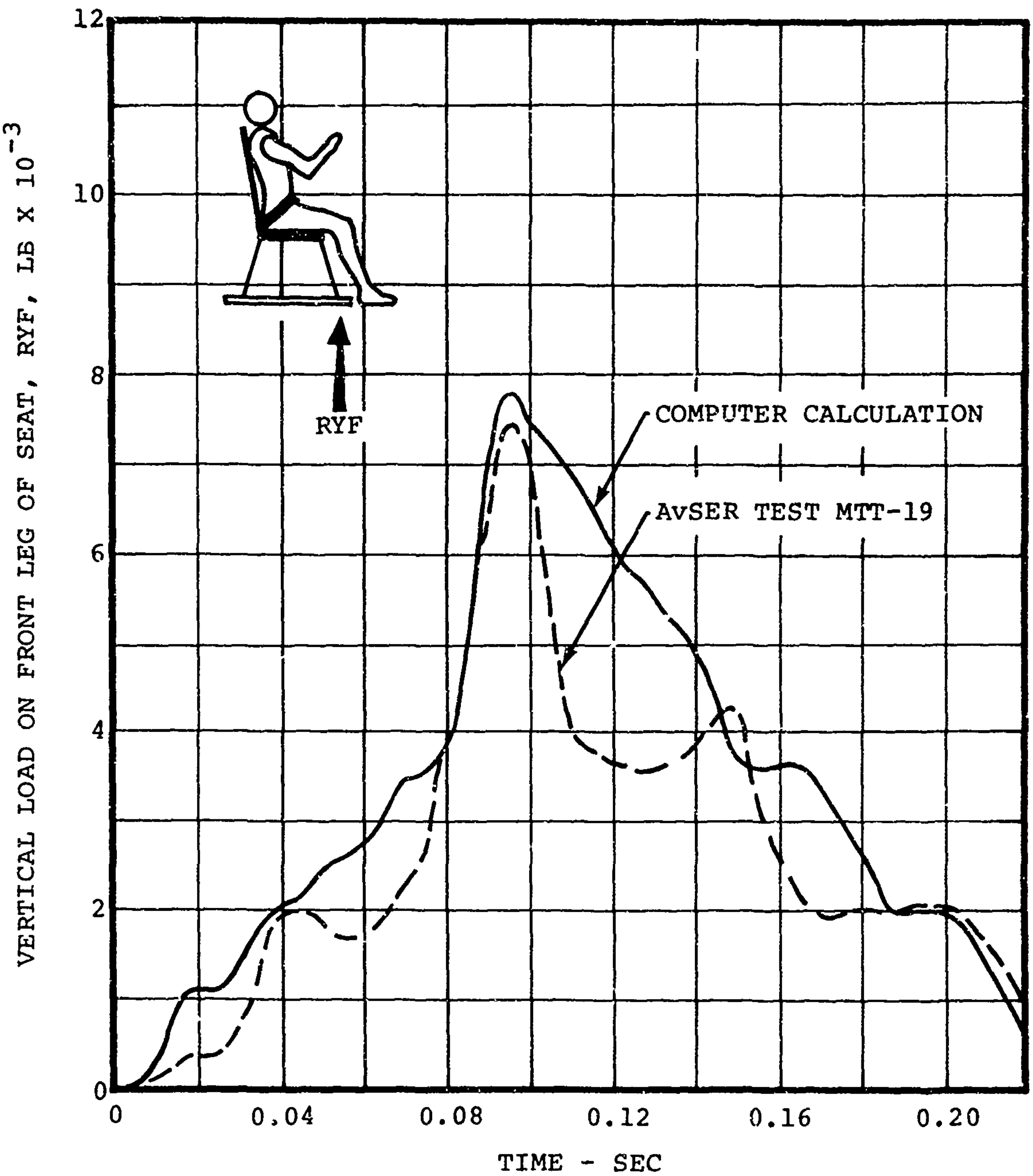


Figure 20. Comparison of Experimental Results With Computer Calculation of Vertical Load on Front Leg of Seat for Case MTT-19.

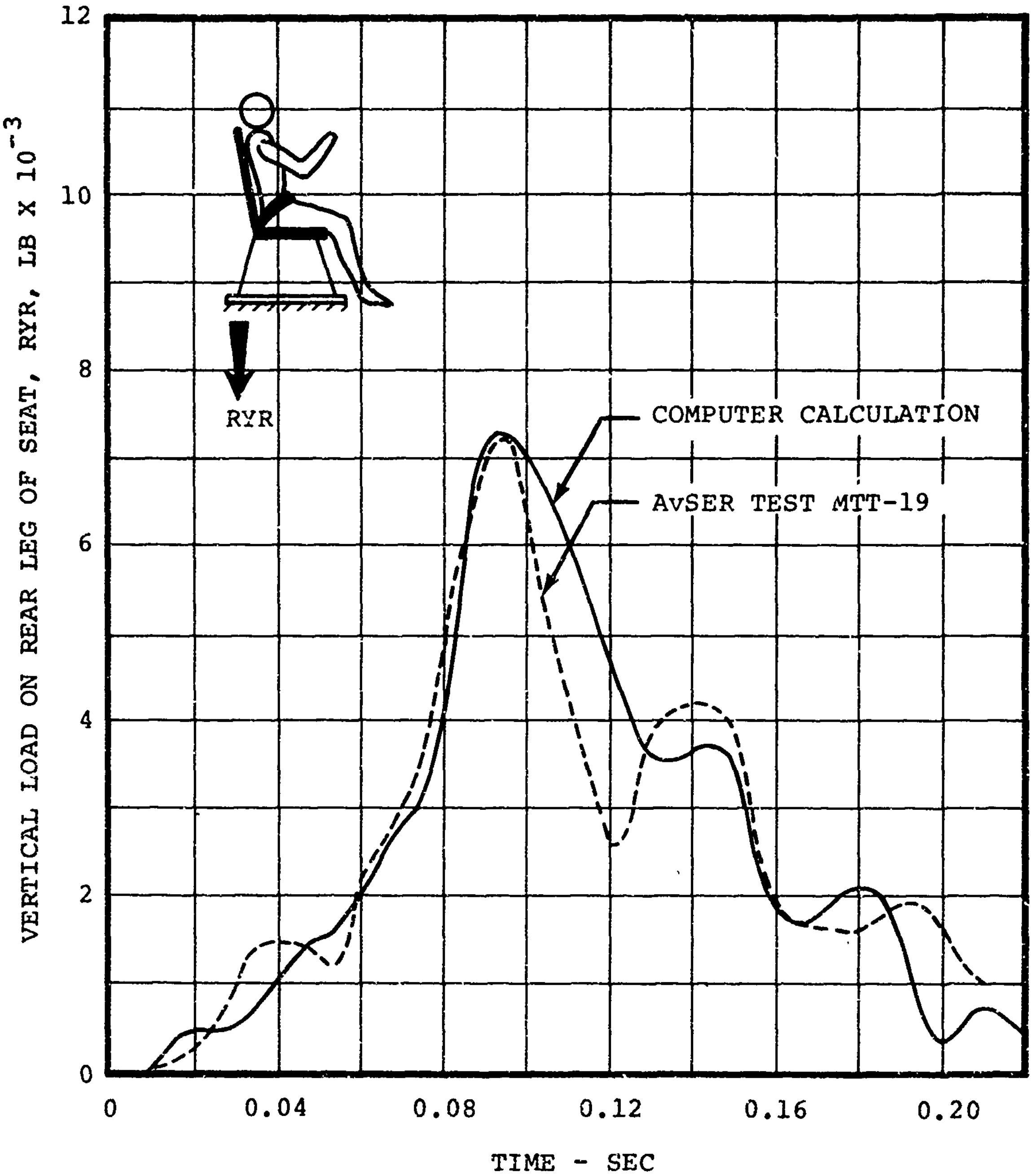


Figure 21. Comparison of Experimental Results With Computer Calculation of Vertical Load on Rear Leg of Seat for Case MTT-19.

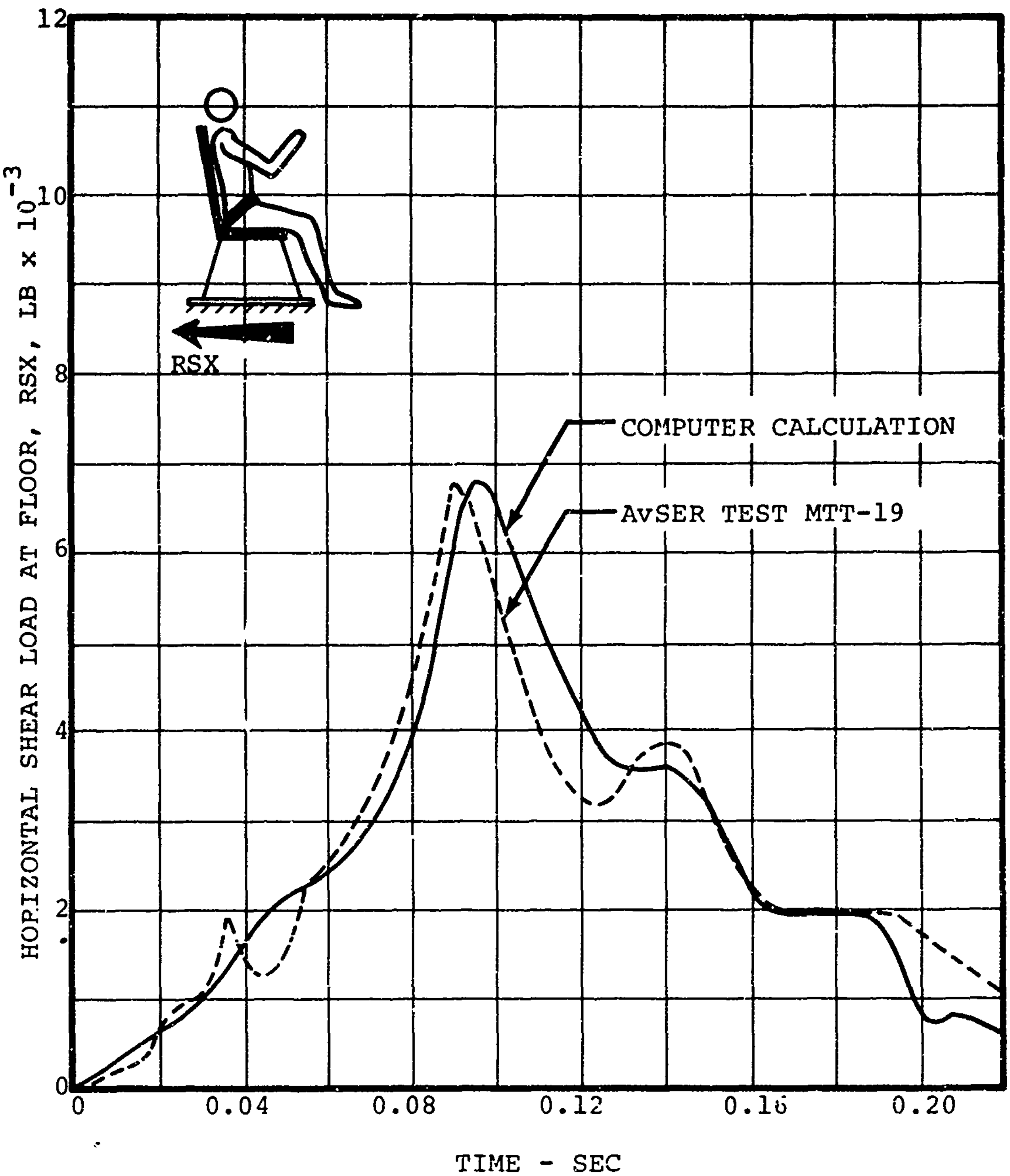


Figure 22. Comparison of Experimental Results With Computer Calculation of Horizontal Shear Load at the Floor for Case MTT-19.

mostly for commercial applications. In general, hardware developed for the military, if accepted, could be used by the general public; the reverse, however, is not true. Hardware developed for use by the public does not generally meet strength requirements established by the military. Ironically, quite often even hardware developed for use by the military does not meet strength requirements.

A considerable amount of effort during this program was spent in locating available hardware to examine for possible use.

The buckle information gathered is summarized in Table IX and was obtained through correspondence with the manufacturers. Only two of the buckles, Nos. 2 and 4, were available.

TABLE IX. BUCKLE SUMMARY

Buckle Number	Strength	Release Mechanisms	Availability	Shape
1	Lap-belt direction, 3100 pounds (slight distortion); fitting remaining operational and releases. Crotch strap and shoulder straps directions, 4500 pounds; fitting fully operational.	Quick Release Rotary	In Production	Round
2	Peak sled deceleration, 35G, 0.025 sec duration.	Quick Release Rotary	Off the Shelf	Round
3	Loop load 6200 pounds for 7075-T6. Loop load 5770 pounds for 6061-T6. Peak sled deceleration, 42.5G.	Quick Release Knob Downward Stroke	Prototype Available	Square
4	2000 pounds.	Quick Release Rotary	In Production	Round
5	2500 pounds proof load. 4000 pounds ultimate load.	Lever	Prototype Available	Square
6	Not available.	Quick Release Push-Lift	In Production	Rectangular
7	40G	Quick Release Squeeze-Turn	Prototype Available	Round
8	20G	Quick Release Pulling a Strap	Off the Shelf	

No additional information other than that shown in Table IX was available for buckle No. 1 except that the latest model is inertia proof and anti-knock proof, and the buckle is used on the aircrew restraint system of the F-111E aircraft.

Buckle No. 2 is designed in accordance with CAA-TSO-C22 for commercial and private aviation use, although the buckle has been improved from time to time in attempts to qualify it for use in military aircraft. The static tensile strength for the buckle is not specified in the company literature; however, during the testing program performed in support of this program, the buckle failed at 2700 pounds of tensile load. The buckle was also tested dynamically in March 1970 by the Federal Aviation Administration with a test dummy weighing 198.5 pounds, indicating that the structural integrity of the buckle is capable of withstanding impact loads of better than 35G for short-duration decelerations.

Buckle No. 3 was tested at Wayne State University in January 1971 using an experimental seat mounted on a test sled in a forward-facing direction and a 50th percentile male dummy weighing 163 pounds. The test indicated that the buckle is capable of withstanding 42.5G for short-duration decelerations under the conditions tested.

The 6200-pound loop load strength reported for the 7075-T6 aluminum body material is equivalent to a 3100-pound tensile load, while the 5770-pound loop load for the 6061-T6 aluminum material is equivalent to a 2885-pound tensile load. Cyclic testing and release load testing were also performed on this buckle and documented in a manufacturer's report.

No dynamic test data were available for buckles Nos. 4 and 5. The dynamic load data shown in Table IX for buckles Nos. 7 and 8 were obtained without any backup information about the conditions under which they were tested.

Table X shows information gathered concerning adjusters. Two models of the adjuster-2 hardware were available for inspection. This adjuster is not adequate in its present configuration. During tests, the webbing slipped through the adjuster all the way to the lapped seam. Different modifications have been tried and tested. The latest one has a continuous plate above the gripper cam with serrations on the side facing the gripper so that the webbing going between the gripper and the plate will be squeezed between the serrations and the gripper teeth. This modification has been tested and performed satisfactorily.

Another feature of this adjuster is the 2-to-1 adjustment ratio. Two inches of webbing must go through the adjuster in order to take up 1 inch of slack.

There are no retractors on the market today suitable for military application. Existing retractors, the more recent ones

TABLE X. ADJUSTER INFORMATION			
Adjuster Number	Strength	Number of Straps	Availability
1	Damage to the Webbing at 2700 Pounds	Single Strap	In Production
2	Cuts the Webbing at 2700 Pounds	Double Strap	In Production
3	Not Available	Single Strap	Prototype Available

of the automatic lock type, are used on lap belts in automobiles and they have been very recently introduced for passenger lap belts in commercial and private aircraft. These retractors do not have any manual provisions for tightening other than grasping the webbing and pulling it toward the retractor. The slack webbing thus produced is retracted by force of the recoil spring. Another type of retractor has very recently been introduced by a foreign automobile manufacturer. This retractor operates like an inertia reel; i.e., the lap belt is free to unreel against a small spring force until a strap acceleration of approximately 2G occurs. The retractor then locks and restrains the pelvis. This retractor is not directly applicable to aircraft because it provides no maneuver restraint.

WEBBING MATERIALS

The first lap-belt restraint was made from leather;[87] however, it is uncomfortable and later restraints in aircraft used cotton material. Leather continued to be used for some hospital restraint applications. Today, restraint systems in both military and private aircraft and automobiles are most often made from synthetic fiber webbing such as nylon and polyester. Reference 88 reports the results of service-life testing performed on cotton, nylon, and rayon lap-belt webbing. A higher incidence of failure was recorded for the cotton belts than for the nylon or rayon belts. In addition, cotton webbings are relatively heavy and bulky in comparison to the synthetic fibers. Restraint systems for automobiles and private and commercial aircraft use nylon fiber webbings almost exclusively. The reason is esthetic, as nylon can be dyed to match the colors of the car or aircraft interiors better. This is done at the expense of higher elongation, however, which results in passenger dynamic overshoot.

Restraint systems in military aircraft use both nylon-fiber and polyester-fiber webbings. These webbings are defined by a number of Military Specifications, the most important of which are MIL-W-4088 for the nylon webbings and MIL-W-25361 for the polyester webbings.

With regard to service life, neither polyester nor nylon are adversely affected by cold or rain since they are not subject to mildew. Both are affected by exposure to sunlight, however. Under glass, polyester is practically unaffected by ultraviolet; but nylon still loses tensile strength after prolonged exposure whether under glass or not. Additionally, heat can be a degrading factor, particularly on nylon, when long exposures to temperatures in excess of 150°F are encountered.

Abrasion resistance of nylon in general is somewhat better than for polyester webbings. The weave pattern used for a particular webbing, however, can greatly influence its abrasion resistance characteristics. Use of larger filament yarns for both nylon and polyester webbings can also increase abrasion resistance.

Research for improved nonmetallic fibrous materials continues. However, most of this research is done for specific purposes, and materials are developed for specific applications. NASA, for example, has developed many nonflammable and fire-resistant nonmetallic materials for spacecraft usage, achieving a high degree of fire safety within the Apollo spacecraft. The Air Force is also involved in research for nonflammable fibrous materials. The need for this type of material has been emphasized by aircraft accidents involving postcrash ground fire in which personnel have been injured or lives lost. Presentation of some of the fibrous materials developed and/or investigated by NASA and the Air Force (with emphasis on space applications)[89] follows.

Asbestos Fiber

Undoubtedly, the highest degree of nonflammability can be obtained with inorganic fibers such as asbestos and fiberglass. Asbestos, a natural mineral fiber, is not used in any exposed areas because of the tendency to shed particulate matter in the spacecraft atmosphere. This shedding is caused by the short-staple length of the individual fibers which work loose from the fabric surface with minimal manipulation. However, asbestos is used in composite layups in which the asbestos is contained within an assembly. Assemblies containing asbestos exhibit a high degree of resistance to the conductive passage of heat and are used extensively in the spacecraft for containers that have flammable contents.

Glass Fiber

Fiberglass is the inorganic glass fiber used most extensively within the spacecraft. The type of fiberglass used almost exclusively is called Beta fabric. This fiber is characterized by an extremely fine diameter which permits the fabrication of textile structures that provide the maximum in flexibility and performance characteristics within the limits of the inherently low abrasion resistance, a characteristic of fiberglass.

Polyamide Fiber

Polybenzimidazole (PBI) is a polyamide fiber that was developed by the Air Force. It has a breaking strength of 4.5 grams per denier and retains 50 percent of its tensile strength at 700°F. In the spacecraft, PBI is used mostly in the form of webbing, tapes, and cords that are required to withstand dynamic flexing. The fiber is completely nonflammable in air, but it does burn slowly in oxygen environments. The burning rate is dependent upon the textile geometry. The more dense constructions have the slower burn rates. The higher relative flammability of PBI than fiberglass is a minimal hazard necessary to obtain performance characteristics that are not obtainable from fiberglass. The cost of the fiber is currently high. The Air Force is initiating a large-scale evaluation of PBI flight clothing, and the other military services are conducting evaluations. If sufficient demand is generated to warrant large-scale production, it is projected that unit costs could be reduced greatly. The natural color of PBI is golden brown, and some success has been achieved in initial attempts to dye the fiber; i.e., PBI fibers have been coated to change the color, but the penetration of intramolecular spaces with coloring matter required for true dyeing has not been achieved.

Teflon Fiber

Another fiber that has essentially the same flammability characteristics as PBI is Teflon. In the bleached form, Teflon is used for the astronaut's shirt-sleeve garment called the intravehicular cover garment. Fiber tenacity is relatively low (approximately 1 gram per denier) but is adequate for spacecraft usage. The high chemical resistance and the low frictional surface characteristics of this fiber should suggest some specialized end uses.

Metallic Fibers

Another group of high-temperature fibers that has been used in the space program is the metallic fibers, which are available in fine-filament form (approximately 1/2-mil diameter). Fabrics that have the flexibility and sewing characteristics of

conventional textiles can be woven of metallic fibers. A Chromel-R is a single-drawn, nickel/chromium-alloy fiber. A bundle-drawn Karma fabric is being considered as the outer shell of an advanced suit that is currently under development. This fiber is also a nickel/chromium alloy, but is less costly than Chromel-R because multiple filaments are drawn at the same time. Stainless steel fiber is available and is being used extensively in industry to reduce the static electricity propensity of floor coverings made from synthetic fibers.

Durette Fiber

Durette (X-400) is a recently developed material made from a modified aromatic polyamide. Durette is nonflammable in air and in moderately enriched oxygen atmospheres. The tenacity of the material is in the range of 4 to 5 grams per denier, and other physical properties are good. The natural color is golden, and developmental effort to dye the fiber with colors of requisite fastness is under way. The fiber producer is promoting commercial applications for this material.

Fabrics designated X-410 and X-420 are modifications of the X-400 fabric and are available only in black shades. They have better flame resistance than X-400 especially in oxygen-enriched atmospheres, and hence, are of interest for future manned-space applications.

Fypro

Fypro is another modified aromatic polyamide similar to Durette, but made by a different proprietary process. The natural color is brown and physical properties are good. The material is nonflammable in air, but minimal oxygen enrichment of the test environment will cause flaming.

Kynol

This is a recently developed phenolic-type fiber. It is orange-yellow in color and will not burn in air although it will burn in oxygen-enriched environments. The fiber will retain its whole-fiber identity when exposed to flame temperatures up to 2500°C. Current applications are mostly in felts and batting-type structures, but the manufacturer has indicated that significant progress has been made in improving the spinnability of the fiber so that conventional knitted and woven fabrics should be available in the near future.

Other Fibers

Foremost among the more conventional fire-resistant organic fibers that have been evaluated by NASA is Nomex. Physical

properties are very good, but slight oxygen enrichment of the atmosphere will produce flaming and, under some conditions, it will burn in air. Other fibers that will not burn in air are Saran and the modacrylics. An off-the-shelf fabric containing these two fibers composed the curtains of the mobile quarantine facility used to transport astronauts to the Lunar Receiving Laboratory. Because of the air transport involved, the curtains and other interior components of the van had to meet the current Federal Aviation Administration airworthiness standards.

Fabric Data

Rather extensive testing and evaluation have been conducted on the various fabric materials covered in the foregoing discussions. A summary list of these fabric materials, along with significant performance characteristics and other pertinent data, is presented in the Restraint System Development section.

The Air Force has extensively tested some of the materials.[90] A discussion of limitations of these materials follows.

One of the most important material properties for use in restraint systems is the force-versus-percent-of-elongation characteristic. Unfortunately, dynamic data are not available for the nonflammable materials discussed, and only limited data are available for webbing materials widely used in present restraint systems. For this reason, the static force-versus-percent-of-elongation characteristics of different types of nylon and polyester webbings were used in the analysis conducted in this program. Additional data are included in Appendix II. Available dynamic-versus-static data are shown in the Variables Analysis section. These data show that, for both the nylon and polyester webbings, the dynamic failure load is higher than the static failure load. Also, both webbings exhibit stiffer force-versus-percent-of-elongation characteristics under dynamic loading. That is, the slope for the dynamic data curve is greater than the slope for the static data curve. Both of these conclusions are very important with regard to using the static force-versus-percent-of-elongation data in the analysis. Since these conclusions are applicable for the velocities considered in the analysis, the results of the analysis are conservative.

Energy-absorbing types of webbings were also considered in the analysis The principal advantages of energy-absorbing webbing are: (1) reduction of maximum load that the webbing exerts on the occupant and (2) reduction of amount of elastic energy stored in the webbing. Two webbings of this type were considered. The principle of energy absorption for the first

webbing material tested depends on a core warp of fiberglass which breaks at a design load. The outer cover of nylon warp then takes over the loading, gripping the fiberglass until it breaks again. The construction of the webbing varies, depending on the type of force-versus-percent-of-elongation curve desired. The general shape for the force-versus-percent-of-elongation curve for this webbing is shown in Figure 23.

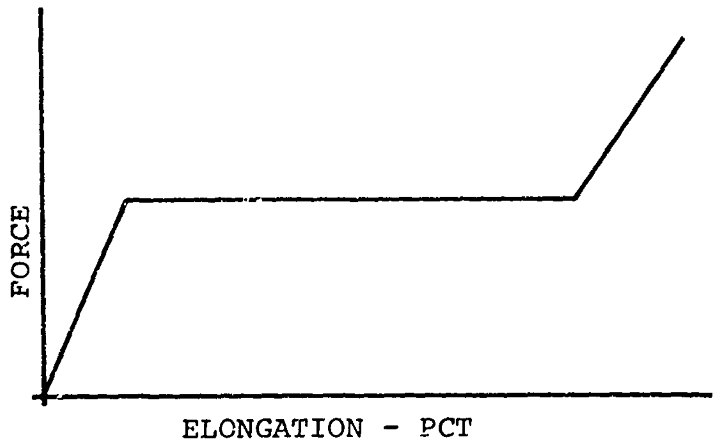


Figure 23. Force-Elongation, Energy-Absorbing Webbing.

The construction of the second type of energy-absorbing webbing differs greatly from the first. It is made of polyester, and the energy absorption is produced by the filaments themselves. The polyester filaments are heat shrunk from their original sizes and they do not return to the shrunk dimensions after the application of a load. This has the effect of plastic deformation, and this property provides the energy absorption capability of the material. The general shape for the force-versus-percent-of-elongation curve for this webbing is shown in Figure 24.

The National Bureau of Standards, Office of Vehicle System Restraints, has tested both webbings. However, all information concerning these energy-absorbing webbings is proprietary, and for further information the manufacturers should be contacted.

Still another energy-absorbing webbing material is undergoing evaluation for parachute applications at the U. S. Naval Aerospace Recovery Facility. The material is made by stitching together two pieces of webbing. The two pieces of webbing separate at a constant load by breaking the stitches holding

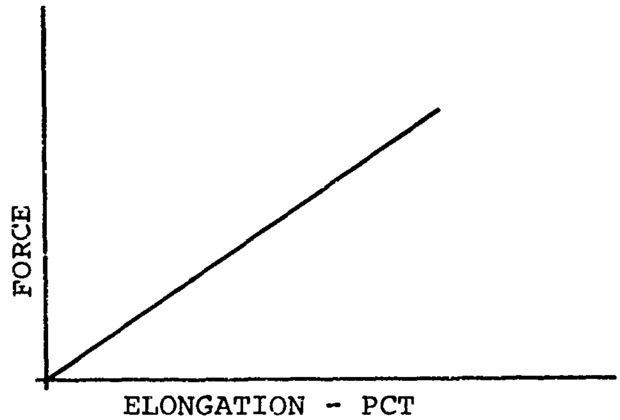


Figure 24. Force Versus Elongation.

them together. The constant breaking force can be varied by increasing or decreasing the number of stitches. Because of its construction, the material does not appear to be suitable for use in aircrew restraint systems. Thus, it was not considered in the analysis.

Weave Pattern

The weave pattern can affect the abrasion resistance of a webbing. It can also affect the force-elongation characteristics of the webbing. The following discussion, taken from Reference 91, explains some of the reasons. First, the elongation of webbing under a load can be attributed to one of three characteristics: (1) the inherent elongation of the fiber itself, (2) elongation resulting from plastic deformation of webbing that has been shrunk during the dyeing and treating process, and (3) elongation caused by the weave configuration.

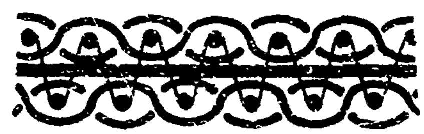
Inherent elongation (elongation which is present in the basic yarn as received from the manufacturer) can vary widely. A few of the fibers which have either been used, or suggested for use, in restraint systems are fiberglass which has approximately zero elongation, high tensile rayon (6 to 7 percent elongation), polyester (11 percent elongation), and nylon (16 to 17 percent elongation). The military generally uses either nylon or polyester in lifesaving equipment. Polyester is currently being used by both the Air Force and Navy for pilot restraint systems. However, for many years nylon was used exclusively, and it is still being used exclusively for decelerator systems such as parachutes.

Elongation due to shrinkage again varies widely with the type of yarn as well as the methods of handling it. Nylon, for instance, will shrink when wet at room temperature. On the

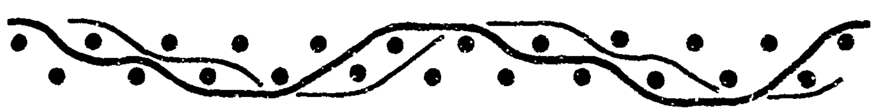
other hand, polyester, as delivered, is stable to approximately 180°F and will not shrink, wet or dry, until subjected to temperatures in excess of this. Unfortunately, it is necessary to subject polyester to considerably higher temperatures in order to dye it, and, under these circumstances, it will shrink considerably more than nylon. The military has found it necessary to yarn-dye polyester and then heat stretch it in order to maintain its low elongation quality. This results in an expensive yarn which is still not entirely satisfactory from a color standpoint. Elongation from shrinkage comes early during load application, resulting in little actual energy absorption.

In order to explain the elongation caused by the weave configuration, Figure 25 illustrates three types of weave configurations currently being used for seat belt webbing. The webbing is viewed from the edge; the dots indicate filling threads or cross shots, and the solid lines indicate the longitudinal warp. In the top right drawing, which is of the two-up/two-down twill used in the pebble weave, four-way, and six-way herringbone twills, it is seen that the warp yarn has a considerable amount of crimp. When load is applied, this crimp will straighten out and result in what is known as mechanical elongation. Since mechanical elongation comes early under loading, it absorbs little energy and, therefore, is not desirable.

TWO-UP/TWO-DOWN TWILL



DOUBLE-PLAIN WITH HEAVY STUFFERS AND ONE-UP/ONE-DOWN BINDER



TWO-UP/FOUR-DOWN TWILL WITH THE BACK FILLING

Figure 25. Filling Cross Sections.

The top left drawing shows a two-ply weave with stuffer yarn such as was used with cam-type buckles. This weave consists of two woven layers with stuffer yarn lying flat between them; layers are held together by binder threads which extend to both surfaces. Since the stuffer yarn possesses no crimp, it will supply a minimum of mechanical elongation. While this configuration is most desirable from the standpoint of low mechanical elongation, it results in a coarse, heavy, thick material which would be impossible to draw through most adjusters.

The bottom drawing represents a two-ply weave in which the warp threads extend to both surfaces in such a way as to supply longer straight runs and, thus, lower mechanical elongation than the first weave, but still slightly more than the second. This results in a soft material somewhat more susceptible to abrasion and roping. It has the advantage of supplying a rather low mechanical elongation and is easily adjustable. In relation to weight, this weave will exhibit the best efficiency. This type of weave is employed by both the Air Force and Navy.

The weave pattern also plays a part in tensile efficiency. The more crimp that the webbing has, the lower this efficiency will be since the warp yarns are being pulled against the filling in such a way as to cause friction damage. In the stuffer weave, very little tensile strength will be gained in the actual woven layers since they will have a great deal more mechanical elongation than the stuffer. The stuffer, therefore, will become the main load bearing material and will break first.

Weather-Resistance Characteristics

Weather resistance is an area about which there is very little information. Certain fibers, such as rayon, cotton, etc., are subject to mildew, and test methods are available to evaluate loss of strength when mildew attacks.

The loss of tensile strength by any of the fibers through exposure to sunlight is almost impossible to gage accurately. The only way to test for this is to actually expose the material to sunlight for long periods of time. Such tests have been conducted by both the military and the yarn manufacturers, and it was found that tensile strength is lost as a result of ultraviolet exposure. The degree of degradation varies greatly, depending upon where the material is exposed, how much actual sunlight is received, and under what conditions such exposure takes place. Some tests conducted by the military have indicated that nylon can lose as much as 50 percent of its tensile

strength after 1 year of constant exposure to direct sunlight in areas like New Mexico. This loss is held to less than 15 percent when the material is behind glass which tends to filter the ultraviolet. In addition, the samples in New Mexico had sand mixed into them and some of the loss might have come from internal abrasion.

Abrasion Resistance

Considering abrasion resistance, all of the yarns currently being used for safety belt webbing are composed of a great many very small filaments, almost invisible to the naked eye. When subjected to friction over metal parts, such small filaments will break, causing a reduction in tensile strength as well as an increase in thickness and fuzzy appearance. The type of weave will affect the degree of such abrasion. The longer the exposed area of yarn on the surface, the greater the susceptibility. From this standpoint, the second weave pattern is the least susceptible to abrasion damage and the third, the most susceptible. For many years the military has been using coatings (plastic and latex) to increase the service life of webbing materials. Additional protection can be provided by adding twist which will further limit the exposure of individual filaments to surface abrasion.

The higher the inherent elongation in yarn, the less susceptible that yarn is to abrasion; thus, nylon has the best abrasion characteristics of any of the suggested or currently used fibers. Glass, on the other hand, is so brittle that it can be broken by merely bending.

Figure 26 shows eight additional weave patterns most commonly used by leading weavers.

Threaded Attachments (Stitched Seams)

The strength and reliability of stitched seams must be insured by using the best known cord sizes and stitch patterns for a specified webbing type. The stitch patterns and cord sizes used in existing high-strength military restraint webbings appear to provide good performance. The basic stitch pattern used in these harnesses is a W-W configuration for single lapped joints. Research by the U. S. Naval Aerospace Recovery Facility (NARF) has reaffirmed the adequacy of basic W-W stitch patterns. The research also revealed that a larger size cord with fewer stitches per inch gave superior performance to the No. 4 MIL-T-7807B cord currently being used. On the basis of this research, the 50-pound strength No. 6 cord at 4-1/2 to 5 stitches per inch is recommended (see Figure 27).

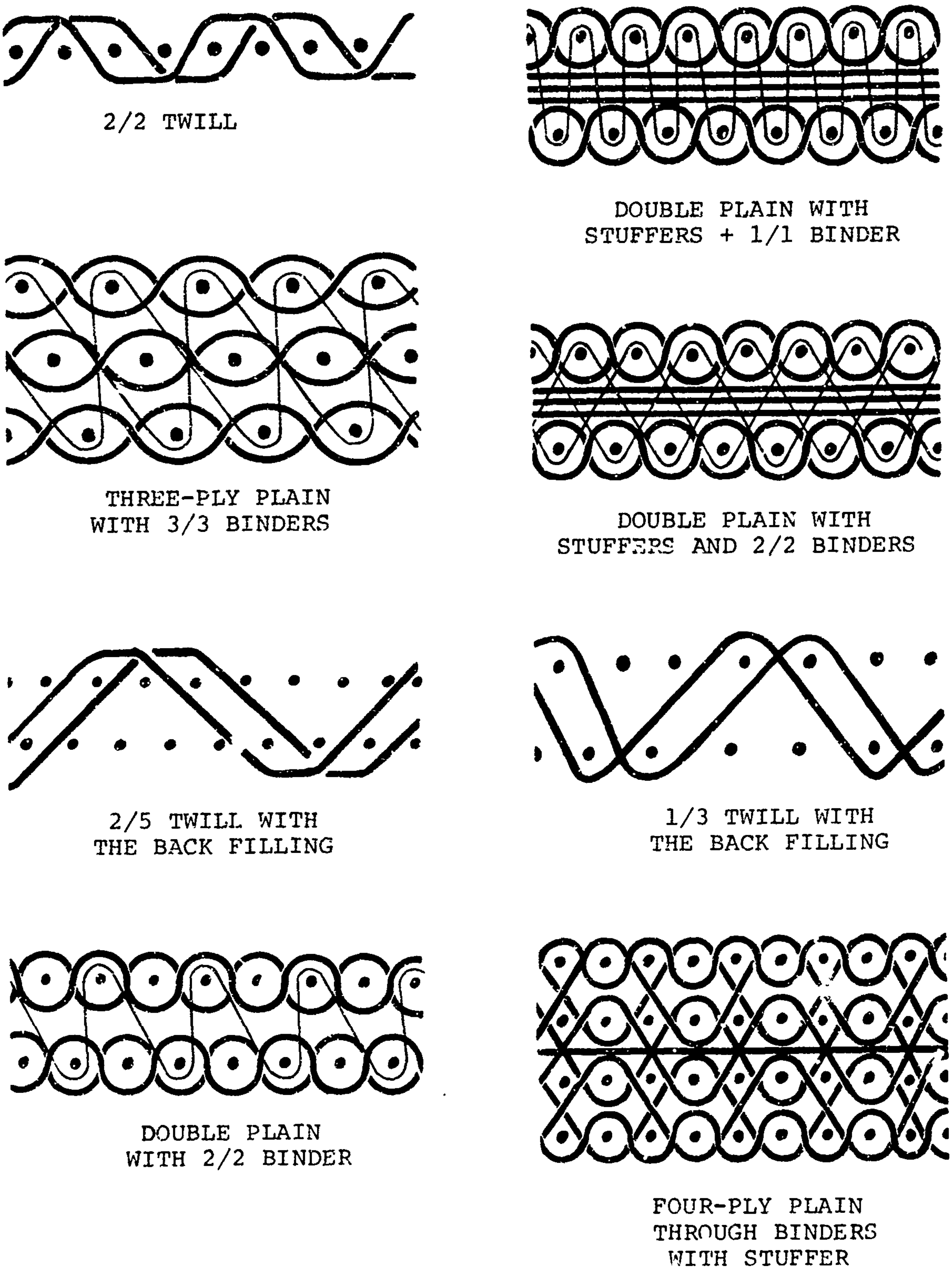


Figure 26. Filling Cross Sections of Different Weaves.

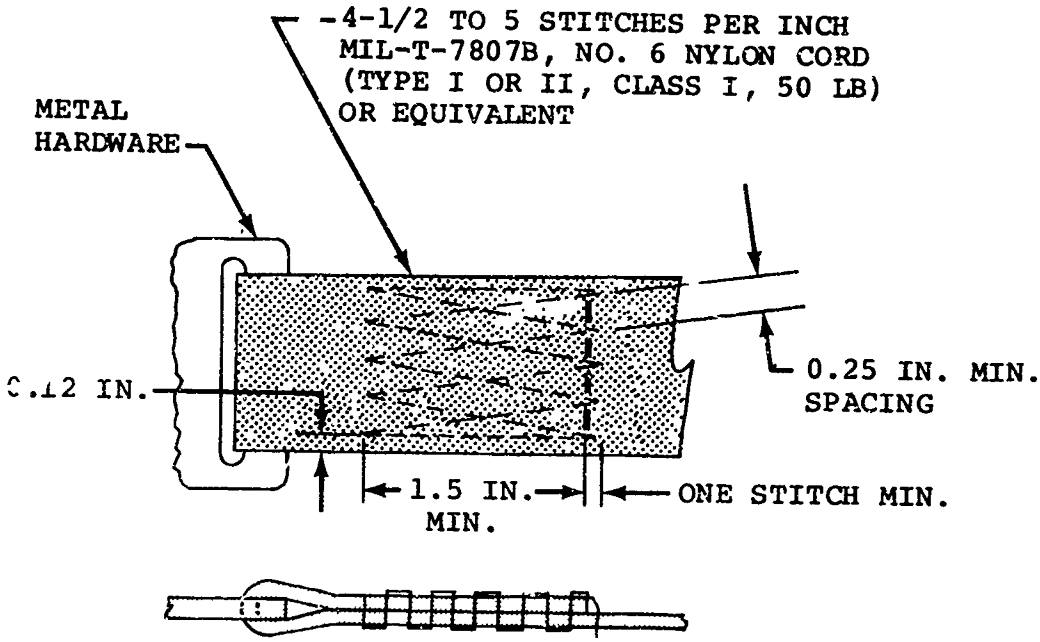


Figure 27. Stitch Pattern and Cord Size.

The heavier cord may also be expected to provide better resistance to sunlight degradation and abrasion. The use of the 50-pound cord results in a minimum strength of 160 pounds per inch for a single lapped joint or 320 pounds per inch for a looped joint. The total length of stitch needed can thus be determined by the total required load.

It is anticipated that the strength of stitched joints will decrease with age because of normal weather exposure and because of the normal dust and grit collection between the webbing surfaces which can gradually abrade the cords. A 50-percent increase in the total stitch length required is recommended to offset the normal aging strength decrease as well as the possible abrasion strength decrease. Covering the stitch joints to provide wear protection for the cords is also recommended.

Unpublished data from comparative tests of five stitch patterns very recently performed by NARF indicated better performance by two new stitch patterns than the basic W-W pattern. The five stitch patterns tested are shown in Figure 28. These patterns were sewn in Types XIII and XXII of MIL-W-4088 nylon webbing used for parachutes. Three samples of each stitch pattern were tested. Table XI shows the results of the first test series. Because of the low number of total stitches, the

PATTERN 1
5 STITCHES/INCH

PATTERN 2
7 STITCHES/INCH

PATTERN 3
5 STITCHES/INCH

PATTERN 4
5 STITCHES/INCH

PATTERN 5
5 STITCHES/INCH

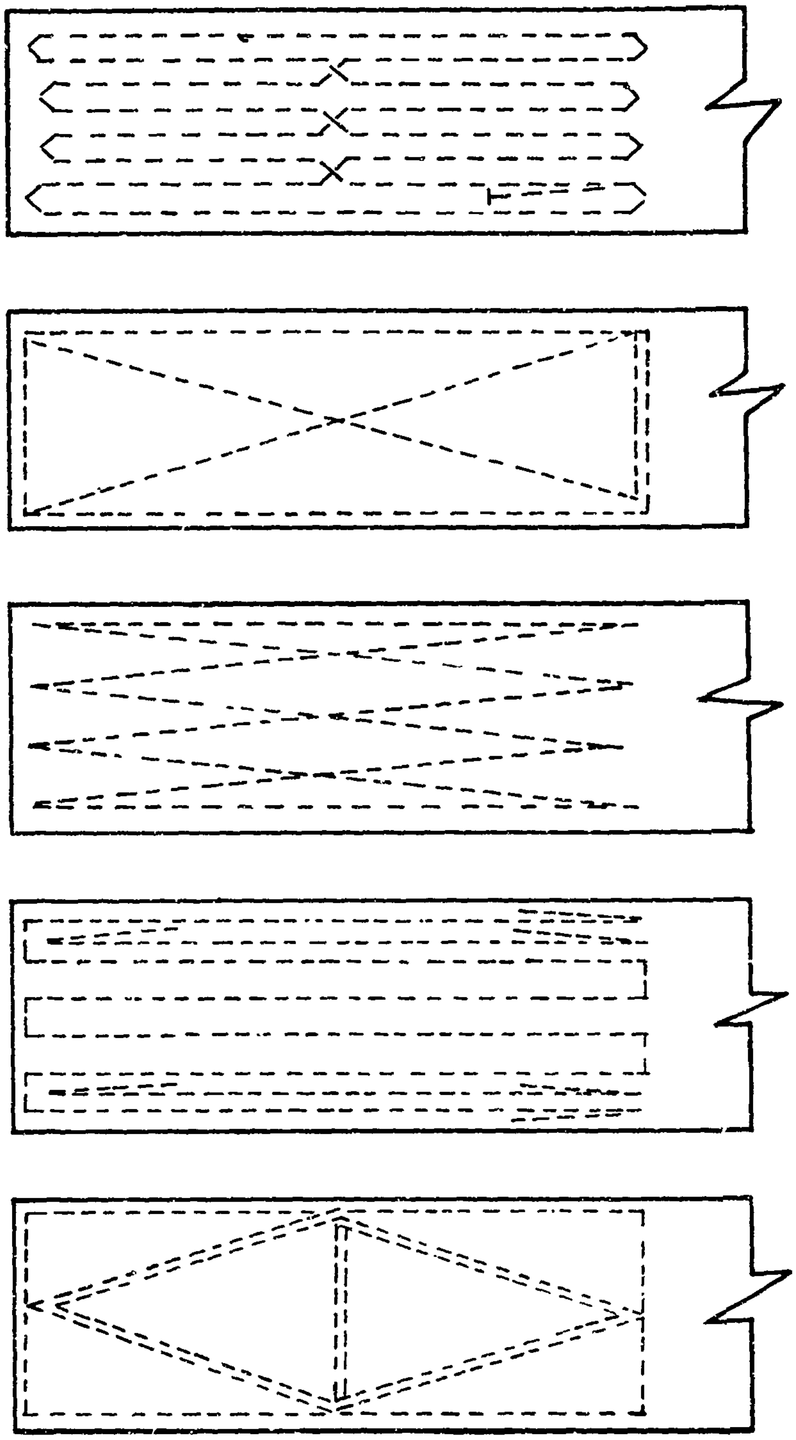


Figure 28. Stitch Patterns Tested.

TABLE XI. BREAKING STRENGTH OF STITCH PATTERNS (TEST SERIES ONE)											
	Sample No.	Webbing and Stitch Type									
		A-1*	A-2*	A-3*	A-4*	A-5*	B-1*	B-2*	B-3*	B-4*	B-5*
Breaking Strength (lb)	1	4835	5040	5645**	4975	5150	5450	5960	5430	5315	5550
	2	4675	4640**	5680**	4880	4935	5420	5780	5620	4650	5420
	3	4545	5060**	5190**	4740	4500	5710	5695	5665	5570	5120
Average Breaking Strength (lb)		4685	4913	5505	4865	4862	5527	5812	5572	5178	5363
Average Break/Average Break W-W (3)		0.851	0.892	1.00	0.884	0.883	0.992	1.04	1.00	0.929	0.963
Approximate Total Stitches		200	190	190	190	180	200	190	190	190	180
Average Break/Stitch (lb)		23.43	25.86	28.97	25.61	27.01	27.64	30.59	29.33	27.25	29.79
Average Break/Stitch/Average Break W-W (3)		0.809	0.893	1.00	0.884	0.932	0.942	1.04	1.00	0.929	1.02

*A designates Type XIII of MIL-W-4088 nylon webbing. B designates Type XXII of MIL-W-4088 nylon webbing. Numerals 1, 2, 3, 4, and 5 designate stitch patterns as shown in Figure 28.
**Webbing broke.

results were inconclusive and the second test series was performed. Patterns 2 and 5 were eliminated from the second series. Table XII shows the results of the second test series. Stitch patterns 1 and 4 exhibited better strength than did pattern 3 (W-W).

TABLE XII. BREAKING STRENGTH OF STITCH PATTERNS (TEST SERIES TWO)							
	Sample No.	Webbing and Stitch Type					
		A-1*	A-3*	A-4*	B-1*	B-3*	B-4*
Breaking Strength (lb)	1	4400	4410	4540**	6340	6420	6215
	2	4710	4740	5080	6480	6490	6060
	3	4820	4360	4870	7200	6500	6070
Average Breaking Strength (lb)		4643	4503	4830	6673	6470	6115
Average Break/Average Break W-W (3)		1.03	1.00	1.07	1.03	1.00	0.945
Approximate Total Stitches		260	270	270	260	270	270
Average Break/Stitch (lb)		17.86	16.68	17.89	25.67	23.96	22.65
Average Break/Stitch/Average Break W-W (3)		1.07	1.00	1.07	1.07	1.00	0.945

*A designates Type XIII of MIL-W-4088 nylon webbing. B designates Type XXII of MIL-W-4088 nylon webbing. Numerals 1, 3, and 4 designate stitch patterns as shown in Figure 28.
**Jaw separation 20 in./min. All other tests at 2 in./min.

The data from this latest research are reported here with permission of the U. S. Naval Aerospace Recovery Facility in order to indicate the latest developments in this area. However, more conclusive information on these or other stitch patterns should be available before the well established and proven W-W stitch pattern is replaced.

VARIABLES ANALYSIS

INTRODUCTION

The possible combinations of variables that can be analyzed and evaluated are almost unlimited. There are many possible lap-belt and shoulder-harness combinations. Restrained occupants vary in size. Response of the seat is a variable and the resultant velocity change may be in any direction with respect to the seat. The magnitude of the velocity is important as are peak input deceleration variables.

To accomplish the variables analysis by testing would become astronomically expensive. Thus, an alternate means was chosen. After consideration of several available two- and three-dimensional computer programs, program SIMULA was chosen for the analysis. To evaluate all of the variables adequately, simple modifications to the program capability with respect to the permissible input defining certain parameters were made.

Aside from the variables and the method of analysis, a criterion of performance is desirable to compare the numerous analyses in a common reference frame. The criterion which was easiest to determine and which considers injury potential as a function of both magnitude and duration of the loads was the weighted impulse criterion (Gadd Severity Index).

VARIABLES

Characteristic Airframe and Seat Response

The response of the occupant is a function of not only the restraint harness but also of the seat and airframe structure force-deformation characteristics. The computer study includes effects of variations in these parameters. Input of various force-deformation curves representative of different types of aircraft structures was accomplished and the response computed.

Direction of Resultant Velocity Change

Crash pulse direction is of primary importance in this study. Pulse directions range from the purely vertical to the purely longitudinal. The lateral components are also important, but the immediately available two-dimensional computer programs cannot handle the third dimension in a straightforward manner.

The two-dimensional model adequately handles the vertical and longitudinal plane, and consequently the analysis matrix includes combinations of vertical and longitudinal components.

Velocity Magnitude

The restraint harnesses were designed for the higher, or 95th percentile, velocity pulses. However, lower velocity inputs can be more severe than the higher inputs, depending on the natural frequency and amplitudes associated with response. Consequently, the effect of occupant response to lower velocity and different shaped crash pulses was also investigated.

Occupant Size

Occupant size is important in the overall evaluation of a particular restraint system. A restraint harness must be designed for the larger occupant, but it must also provide protection to the small occupant. Consequently, designs were evaluated relative to occupant size. Primary considerations were given to the 95th, 50th, and 5th percentile Army aviator.

Peak Input Deceleration

Another important variable is peak G imposed on the harness. This variable was investigated as a function of the load deformation characteristics of the aircraft structure and seat as well as pulse shape.

Restraint System Load Deformation

One of the primary variables is the load deformation characteristics of the harness; these include not only the material load deformation characteristics but also the thickness and width of webbing, the location of tie-down points, and the number of straps. In addition to the basic difference between webbing materials, it is apparent that, since deformation is a function of stress, lower stressed webbing will deflect less than more highly stressed webbing.

Another important factor with respect to elongation is strap angle. The closer the strap axis coincides with the axis of the force imposed, the lower the loading and the less the elongation.

An additional consideration with respect to strap angle is the variation in the effective lengths and load-carrying capabilities as a function of movement. For example, as the lap belt deflects, a lap-belt tie-down strap, because of its forward location on the seat pan, tends to loosen as it rotates about its tie-down point.

Standard Versus Power Inertia Reel

This variable can be evaluated with the computerized analysis technique. Input of the force-deformation curve of the shoulder harness can be made. Consequently, the deflection of the webbing as a function of load can be superimposed on the force that can be exerted by the power source in the reel. Harnesses employing powered inertia reels for upper torso restraint can then be compared to harnesses employing the standard inertia reels. The occupant response can be compared as a function of material properties, amount of free movement in the locking mechanism of the reel, slack, and powered-reel torque and reel-in velocity.

Energy-Absorbing Shoulder Harnesses

An energy-absorbing torso harness provides several distinct advantages over a rigid upper-torso restraint system if the problem of slack produced by stroking can be alleviated. Since the problems associated with increased slack in the restraint system can be simply solved by sufficient inertia reel capacity, this possibility deserved intensive investigation. In summary, an energy-absorbing upper-torso restraint (1) reduces the whiplash effect on the head, thus reducing the possibility of concussion, (2) permits proper orientation of the pelvic structure to minimize the probability of submarining, and (3) reduces the load imposed on the upper torso.

Energy absorption can be provided in the restraint harness either by the use of webbing which progressively fails, by a plastic hinge in the back of the seat, or by an energy-absorbing inertia reel. A trade-off of these considerations is combined with the evaluation of the standard versus power inertia reel described previously.

USE OF PROGRAM SIMULA (SEE ANALYTICAL MODELING SECTION)

Restraint System

The force-deflection relationships for the shoulder harness and lap belt inputs are made separately. The basic curves for each have two loading branches and an unloading slope. The first portion of the loading curve is a polynomial which may be up to 4th degree. The second branch and the unloading branch are straight-line segments

Because dynamic load-deflection relationships were not readily available for the webbings used in the analyses, static load-deflection data inputs were made to the program for most of the analyses. Comparisons between static and dynamic data

which were available led to the belief that the results obtained using the static relationships should be conservative. Runs were made to substantiate the premise. Figures 29 and 30 show static and dynamic load-deflection curves for one width of nylon and polyester webbings.

The difficulty in evaluating coefficients for a 4th-degree polynomial, and the fact that accurate dynamic force-deflection curves were unavailable, led to the decision to approximate the curves with two straight-line loading branches and one straight-line unloading branch. Static load-deflection curves for the webbings used in the analyses are shown in Figures 31 through 34. Superimposed on the figures are the straight-line segments used to approximate the curves for the computer analyses. C_1 is the slope of the initial portion of the curve and C_7 is the slope of the second portion. B is the percent of elongation at which the slope changes. The magnitudes of these variables are summarized in Table XIII for the various webbings.

The program also has available a velocity-dependent term which can be used to raise the force level depending upon the strain rate in the material. Not enough is known, however, about the proper use of this term, so it was used sparingly.

Occupants

The basic occupant variables are shown on Figure 35. The values used in the computer runs for the lengths and weights for a 95th percentile occupant including helmet and armor, a 50th percentile occupant similarly laden, and a 5th percentile occupant without armor are shown in Table XIV. The values used are based upon information obtained from Hertzberg anthropometric data.[92] Although the values are based upon Air Force personnel, they were used since the Hertzberg tabulations are more complete and Army personnel are similar.

The program also requires joint moment resistances due to muscle tension for both normal and extreme ranges of travel and the initial angular configuration of the body. The values for these variables were common for all occupants.

Seat

The basic information required for the seat is the weight, moment of inertia, load-deflection relationships and damping constants for the front legs, rear legs, and the seat pan, and various dimensions. These were the same for all cases.

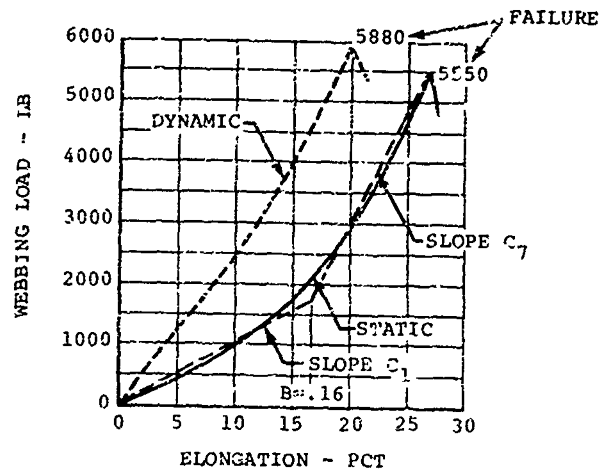


Figure 29. Stress-Strain Curves for MIL-W-4088 (Type VII) Nylon Webbing for Static and Rapid Loading Rates (1.70).

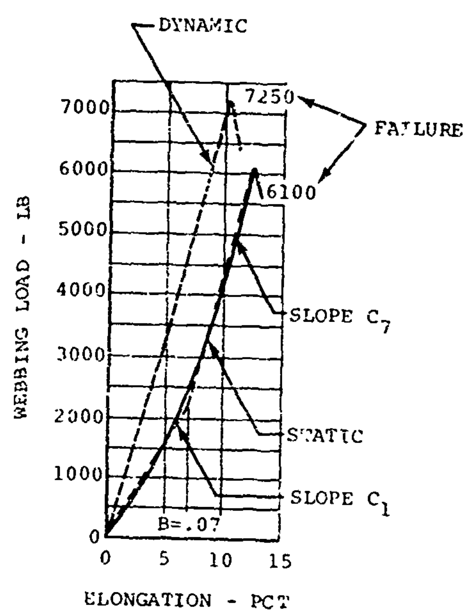


Figure 30. Stress-Strain Curves for MIL-W-25361 (Type II) Polyester Webbing for Static and Rapid Loading Rates (1.70).

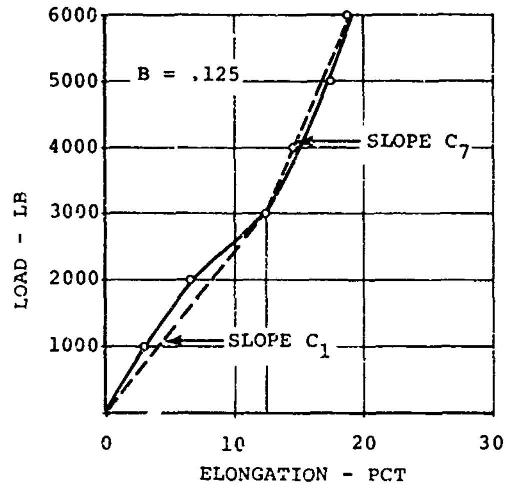


Figure 31. Static Load-Deflection Curve for 2-Inch MIL-W-25361 Polyester Webbing.

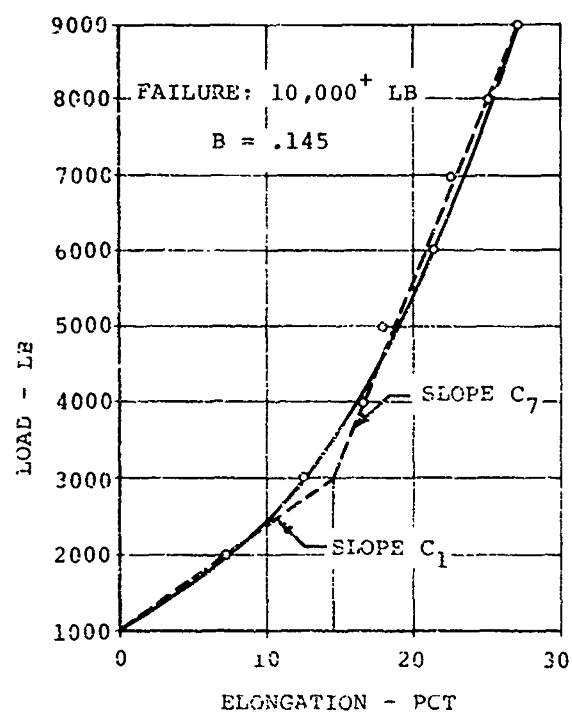


Figure 32. Static Load-Deflection Curve for 2-1/4-Inch Type XXVIII, MIL-W-4088 Nylon Webbing.

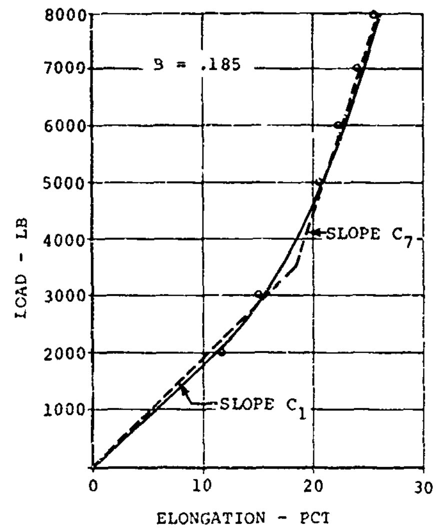


Figure 33. Static Load-Deflection Curve for 3-Inch Type IX, Condition R Nylon Webbing.

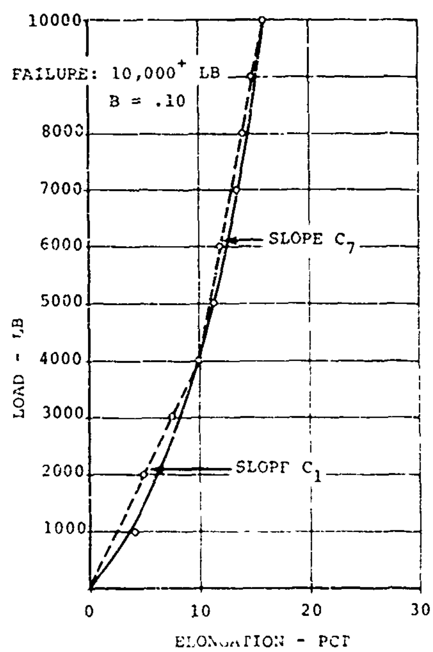


Figure 34. Static Load-Deflection Curve for 3-Inch Type IV, MIL-W-25361 Polyester Webbing.

TABLE XIII. WEBBING PROPERTIES INPUT TO PROGRAM SIMULA				
Webbing		Initial Slope (C_1)	Final Slope (C_7)	Percent Elongation at Slope Change (B)
Width (in.)	Material			
1.75	Nylon	10312	36250	16.0
1.75	Polyester	30714	75000	7.0
2.00	Polyester	24000	44444	12.5
2.25	Nylon	13793	48750	14.5
3.00	Nylon	18362	64000	18.5
3.00	Polyester	39000	103333	10.0

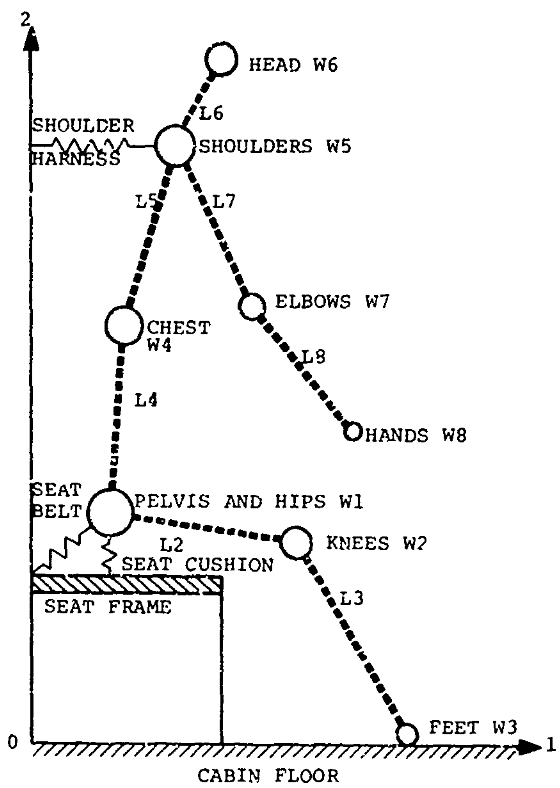


Figure 35. Basic Occupant Variables.

TABLE XIV. LENGTH AND WEIGHT CHARACTERISTICS OF OCCUPANTS			
Body Member	95th Percentile*	50th Percentile*	5th Percentile
Length** (in.)			
L2	17.20	16.03	14.89
L3	21.55	20.12	18.67
L4	11.31	10.54	9.79
L5	10.93	10.21	9.48
L6	7.22	6.74	6.26
L7	12.48	11.63	10.80
L8	16.75	15.62	14.51
Weight** (lb)			
W1	48.9	39.5	32.4
W2	29.9	24.1	19.8
W3	23.3	19.5	16.8
W4	46.8	39.9	23.6
W5	49.1	41.4	25.8
W6	17.3	14.6	12.6
W7	13.0	10.5	8.6
W8	4.7	3.8	3.1
Total	233.0	193.3	142.7

*Body armor included in weights
**Refer to Figure 35 for definition of lengths and weights

Other Required Information

The shape of the input acceleration pulse, the simulation time increments, the ratio of vertical to horizontal acceleration pulse, and various run parameters were also necessary. The values of these variables changed depending upon the analysis desired.

SEVERITY INDEX

The human body is a complex, nonlinear, damped, multi-mass system. It is subject to dynamic response in any of its many modes of vibration. This means that the response experienced by portions of the body may be markedly different from the input pulse applied to the body at the point of impact. Human tolerance data indicate that high forces or accelerations can be tolerated by the body for only very short periods of time, while lower values of these quantities can be tolerated for longer periods of time.

In order to evaluate the injury potential of an impact, some sort of weighted impulse criterion is necessary. The criterion chosen was the Severity Index where injury potential is proportional to the equation:

$$SI = \int_{t_o}^{t_s} a^n \, dt$$

where SI = Severity Index

a = acceleration as a function of time (G)

n = weighting factor greater than 1

t = time (sec)

Published data indicate that a weighting factor should place relatively greater weight upon the acceleration than upon the duration. This is particularly true of skeletal components which are less viscoelastic than soft tissue. The exponent n has a value of 2.5 for the head and face and a lower value for viscoelastic materials such as soft tissue. Research is continuing to expand the application of the severity index; however, existing data are insufficient for predicting chest and pelvic injuries with confidence.

Severity indexes were calculated for these body portions using the 2.5 exponent (same as for the head) because it is still a good indicator of the relative severity of the resulting pulse.

The commonly accepted limiting value of Severity Index for the head is 1000, above which severe injury or death may occur.

VARIABLES ANALYSIS MATRIX

The primary variables chosen for the variables analysis matrix were: (1) restraint system, (2) pulse magnitude, (3) occupant size, and (4) pulse shape. Figure 36 shows possible lap-belt/shoulder-harness combinations which were considered. For each of the lap-belt/shoulder-harness combinations, Table XV indicates possible combinations of the other three primary variables.

BELT	HARNESS
3-inch Polyester	3-inch Polyester
	3-inch Nylon
	2-1/4-inch Nylon
	2-inch Polyester
	1-3/4-inch Polyester
3-inch Nylon	3-inch Polyester
	3-inch Nylon
	2-1/4-inch Nylon
	2-inch Polyester
	1-3/4-inch Polyester
	1-3/4-inch Nylon
2-1/4-inch Nylon	3-inch Polyester
	3-inch Nylon
	2-1/4-inch Nylon
	2-inch Polyester
	1-3/4-inch Polyester
	1-3/4-inch Nylon
2-inch Polyester	3-inch Polyester
	3-inch Nylon
	2-1/4-inch Nylon
	2-inch Polyester
	1-3/4-inch Polyester
	1-3/4-inch Nylon
1-3/4-inch Polyester	3-inch Polyester
	3-inch Nylon
	2-1/4-inch Nylon
	2-inch Polyester
	1-3/4-inch Polyester
	1-3/4-inch Nylon
1-3/4-inch Nylon	3-inch Polyester
	3-inch Nylon
	2-1/4-inch Nylon
	2-inch Polyester
	1-3/4-inch Polyester
	1-3/4-inch Nylon

Figure 36. Possible Lap-Belt/Shoulder-Harness Combinations.

TABLE XV. VARIABLES ANALYSIS MATRIX

Restraint System	Pulse			Occupant Size			Pulse Shape			
Belt Harness	V = 50 fps G_p = 30	V = 40 fps G_p = 25	V = 30 fps G_p = 20	95th Percentile with Armor	50th Percentile with Armor	5th Percentile without Armor	△	◺	◿	◠
ONE BELT-HARNESS COMBINATION	X			X			X			
	X			X				X		
	X			X					X	
	X			X						X
	X				X		X			
	X				X			X		
	X				X				X	
	X				X					X
	X					X	X			
	X					X		X		
	X					X			X	
	X					X				X
		X		X			X			
		X		X				X		
		X		X					X	
		X		X						X
		X			X		X			
		X			X			X		
		X			X				X	
		X			X					X
		X				X	X			
		X				X		X		
		X				X			X	
		X				X				X
			X	X			X			
			X	X				X		
			X	X					X	
			X	X						X
			X		X		X			
			X		X			X		
			X		X				X	
			X		X					X
			X			X	X			
			X			X		X		
			X			X			X	
			X			X				X

Table XV indicates 36 possible computer runs for each restraint system combination. With the 36 restraint system combinations in Figure 36, a total of 36^2 or 1296 computer runs would be necessary if all combinations from Figure 36 and Table XV were attempted. This total number was not run, since only enough runs were needed to establish the desired trend data.

In addition to the basic variables matrix, other considerations were the effect of energy-absorbing webbing and the effect of power inertia reels. Supplementary runs were made to evaluate these effects.

The following paragraphs indicate the reasoning behind choices for the primary variables in the analysis matrix.

Restraint System Combinations

The most popular webbings, especially for military use, are 1-3/4-inch and 3-inch-wide belts made of nylon or polyester. An intermediate point is necessary for each type of webbing to establish whether or not the response varies linearly with belt width. To this end, properties were obtained for a 2-1/4-inch nylon webbing and a 2-inch polyester webbing in addition to the properties for the standard 1-3/4-inch and 3-inch sizes. It was later determined that the 2-inch polyester webbing did not meet the military specifications that it was reported to meet, and it was subsequently dismissed from further consideration.

Pulse Magnitude

Ninety-fifth percentile peak G levels and velocity changes for longitudinal impacts of rotary-wing and light fixed-wing aircraft taken from the Crash Survival Design Guide were used to define the most severe case for pulse magnitude in the variables analysis matrix Lower values for peak G level and velocity change were chosen by reducing the velocity changes by 10 ft/sec and the peak G level by 5G for each increment, resulting in 3 pulses which have approximately one-tenth sec duration if the pulse shape is triangular.

Occupant Size

Three different occupant sizes were considered in the variables analysis matrix: a 95th percentile occupant equipped with helmet, body armor, and a vest-type survival kit; a 50th percentile occupant similarly laden; and a 5th percentile occupant without the body armor. The computer input values for the various portions of the body are given in Table XIV.

The larger occupant is indicative of the maximum loads the restraint system would be expected to restrain in a crash, and the middle occupant represents the average. The smaller occupant is evaluated because a restraint system designed to hold the largest occupants could be dangerous to the smallest ones.

Pulse Shape

The pulse shapes chosen for the variables analysis matrix reflect the fact that a pulse usually builds to a peak and drops off. In most cases, the actual pulse can be accurately idealized by a triangular pulse. Although program SIMULA will accept rectangular, trapezoidal, sinusoidal, triangular, and various combinations of these pulses, crash pulses have been established to be basically triangular.[8] Consequently, the analysis was based on triangular pulse shapes.

RESULTS OF THE VARIABLES ANALYSIS

The initial series of runs was made for a 95th percentile occupant with a helmet, survival vest, and body armor. Three pulse magnitudes were used, all of which were shaped like isosceles triangles. Various combinations of lap belt and shoulder harness widths and materials were used. The results of the initial series of runs are presented in Table XVI. Other results are tabulated in the subsections for specific comparisons.

The results of the initial series of runs indicated that there was little to be gained by considering the intermediate pulse, as the severity indexes were found to vary approximately linearly with increasing pulse magnitude in most cases. Thus, subsequent runs were made only for the high and low energy pulses.

Static Versus Dynamic Webbing Properties

A series of runs was made to compare the effect of the use of static versus dynamic webbing properties in the analyses. The only dynamic properties available were obtained by Haley[93] in drop tower tests. The intent of the tests was to place a 25G load on the webbing within a 5- to 30-msec time span. This resulted in a loading rate of up to 450,000 lb/sec on the webbing. Figures 29 and 30 show the results of the dynamic tests as well as static tests on the same webbings. The webbings used were 1-3/4-inch-wide nylon and polyester.

The results of the analyses are summarized in Table XVII which shows the severity index determined for the head, chest, and pelvis using static and dynamic webbing properties. The input

TABLE XVI. RESTRAINT SYSTEM PERFORMANCE FOR A 95TH PERCENTILE OCCUPANT WITH FULL GEAR FOR VARIOUS RESTRAINT SYSTEM MATERIALS AND CRASH PULSES

Restraint System		Severity Indexes			Maximum Values: Load (lb)		Maximum Values: Deflection (in.)		Pulse	
Belt	Harness	Pelvis	Chest	Head	Belt	Harness	Belt	Harness	ΔV (fps)	G_p (G)
1-3/4-Inch Nylon	1-3/4-Inch Nylon	618	396	429	6631	4262	9.20	11.2	50	30
		447	304	316	5533	3431	8.13	9.02	40	25
		289	205	205	3781	2751	6.85	7.26	30	20
	1-3/4-Inch Polyester	1100	564	433	6715	5378	9.28	4.85	50	30
		488	328	320	5450	4567	8.23	4.12	40	25
		321	201	228	3937	3700	6.98	3.35	30	20
	2-1/4-Inch Nylon	621	427	388	6584	4474	9.16	8.77	50	30
		441	313	279	5244	3826	8.06	7.51	40	25
		276	212	202	3626	3173	6.72	6.25	30	20
	3-Inch Nylon	644	458	349	6572	4960	9.16	7.36	50	30
		450	330	270	5203	4283	8.02	6.38	40	25
		247	200	198	3546	3507	6.74	5.25	30	20
	3-Inch Polyester	856	506	445	6832	5409	9.37	3.85	50	30
		699	397	391	5536	4573	8.30	3.27	40	25
		434	217	260	4004	3711	7.03	2.67	30	20
1-3/4-Inch Polyester	1-3/4-Inch Nylon	572	447	970	6022	4637	3.65	12.1	50	30
		408	260	630	5175	3703	3.31	9.72	40	25
		267	166	363	4181	2795	2.91	7.37	30	20
	1-3/4-Inch Polyester	429	263	355	6034	4654	3.64	4.21	50	30
		350	223	247	5163	3748	3.31	3.40	40	25
		256	171	173	4122	3033	2.89	2.76	30	20
	2-1/4-Inch Nylon	490	375	793	5994	4830	3.63	9.46	50	30
		387	253	547	5143	3865	3.29	7.60	40	25
		254	170	317	4153	2935	2.90	5.80	30	20
	3-Inch Nylon	439	313	627	5970	4902	3.63	7.27	50	30
		388	254	443	5122	3929	3.28	5.86	40	25
		255	177	265	4128	3004	2.88	4.52	30	20
	3-Inch Polyester	423	254	264	6072	4462	3.67	3.19	50	30
		336	211	196	5153	3639	3.30	2.62	40	25
		229	159	140	4044	3213	2.86	2.31	30	20
3-Inch Nylon	1-3/4-Inch Nylon	513	338	560	6423	4404	6.97	11.50	50	30
		370	261	438	4649	3580	6.19	9.41	40	25
		219	170	265	3029	2743	4.95	7.24	30	20
	1-3/4-Inch Polyester	458	326	244	6421	5072	6.97	4.58	50	30
		241	210	206	4666	4325	6.14	3.90	40	25
		162	152	170	2927	3564	4.78	3.23	30	20
	2-1/4-Inch Nylon	502	340	446	6492	4520	7.00	8.86	50	30
		359	265	356	4803	3753	6.21	7.38	40	25
		204	169	228	3037	2918	4.96	5.76	30	20
	3-Inch Nylon	490	335	367	6558	4584	7.02	6.81	50	30
		325	254	283	4788	3912	6.20	5.84	40	25
		197	169	203	3011	3114	4.92	4.68	30	20
	3-Inch Polyester	428	308	243	6592	5301	7.05	3.76	50	30
		344	239	235	4842	4481	6.23	3.20	40	25
		239	173	188	2973	3671	4.86	2.63	30	20
3-Inch Polyester	1-3/4-Inch Nylon	422	376	897	5759	4656	3.54	12.20	50	30
		306	259	629	4470	3763	3.17	9.88	40	25
		202	149	369	3299	2867	2.54	7.56	30	20
	1-3/4-Inch Polyester	302	228	335	5843	4841	3.56	4.37	50	30
		272	210	277	4506	4007	3.18	3.62	40	25
		189	149	190	3330	3114	2.56	2.83	30	20
	2-1/4-Inch Nylon	395	357	783	5711	4880	3.33	9.56	50	30
		304	258	574	4417	3967	3.15	7.79	40	25
		202	157	336	3298	3037	2.54	6.00	30	20
	3-Inch Nylon	336	302	628	5687	4999	3.52	7.42	50	30
		246	226	452	4389	4077	3.14	6.08	40	25
		195	160	290	3303	3154	2.54	4.74	30	20
	3-Inch Polyester	285	203	239	5977	4683	3.60	3.35	50	30
		278	203	225	4576	3904	3.20	2.80	40	25
		208	156	171	3335	3045	2.56	2.20	30	20

TABLE XVII. THE EFFECT OF STATIC VERSUS DYNAMIC WEBBING PROPERTIES ON SEVERITY INDEX, MAXIMUM RESTRAINT LOADS, AND DEFLECTIONS FOR A 95TH PERCENTILE OCCUPANT WITH FULL GEAR

Restraint System		Severity Index						Maximum Load (lb)				Maximum Deflection (in.)				Pulse	
		Pelvis		Chest		Head		Belt		Harness		Belt		Harness		ΔV	G_p
Belt	Harness	Stat.	Dyn.	Stat.	Dyn.	Stat.	Dyn.	Stat.	Dyn.	Stat.	Dyn.	Stat.	Dyn.	Stat.	Dyn.	(fps)	(G)
1-3/4-Inch Nylon	1-3/4-Inch Nylon	618	365	396	275	429	333	6631	5481	4262	4750	9.20	5.56	11.20	5.54	50	30
		447	327	304	234	316	263	5333	4450	4331	3923	8.13	4.74	9.02	4.59	40	25
		289	214	205	165	205	192	3781	3265	2751	3107	6.85	3.81	7.26	3.64	30	20
	1-3/4-Inch Poly-ester	1100	271	56[illegible]	201	433	164	6715	5613	5378	4882	9.28	5.66	4.85	2.23	50	30
		488	326	328	202	320	178	5450	4498	4567	4219	8.23	4.78	4.12	1.9[illegible]	40	25
		321	278	201	181	228	167	3937	3235	3700	3532	6.98	3.78	3.35	1.61	30	20
1-3/4-Inch Poly-ester	1-3/4-Inch Nylon	572	366	447	373	970	748	6022	4803	4637	5314	3.65	2.13	12.10	6.19	50	30
		408	324	260	286	630	539	5175	4081	3703	4302	3.31	1.88	9.72	5.03	40	25
		267	253	166	201	363	347	4181	3391	2795	3330	2.91	1.53	7.37	3.90	30	20
	1-3/4-Inch Poly-ester	429	312	252	242	355	325	6034	4882	4564	5051	3.64	2.16	4.21	2.3[illegible]	50	30
		350	304	223	223	247	261	5163	4166	3748	4025	3.31	1.87	3.40	1.84	40	25
		256	214	171	150	173	165	4122	3436	3033	3052	2.89	1.55	2.76	1.40	30	20

pulses for all cases were shaped like isosceles triangles, and the occupant simulated was a 95th percentile man with helmet, body armor, and a survival vest.

Table XVII shows that in the vast majority of cases the severity index obtained with dynamic webbing properties was lower than the severity index obtained with statically determined webbing properties. In most cases the ratio of severity index determined with static properties to severity index determined with dynamic webbing properties remained fairly consistent as the pulse magnitude was varied. The general trend of the data is indicated in Figure 37 which shows the head severity index obtained for various pulse magnitudes for nylon and polyester restraint systems using both static and dynamic webbing properties.

The notable exception to the general trend of the data in Table XVII is for the high energy pulse on a restraint system composed of a 1-3/4-inch nylon lap belt and a 1-3/4-inch polyester shoulder harness. The severity indexes obtained with the dynamic webbing properties seemed abnormally low in comparison to the general data trends. There are two possible explanations for this. First, there is the possibility that these results are incorrect, although a cursory examination of the input data revealed no obvious discrepancies. The other explanation is that the particular combination of a nylon lap belt and a polyester harness is very sensitive to the rate of loading on the webbings.

In all cases the maximum deflection in both the lap belt and shoulder harness was lower when the stiffer dynamic properties of the webbings were taken into acount. The deflections resulting from the use of dynamic properties were usually about 50 percent of those obtained when the static load-deformation input was used.

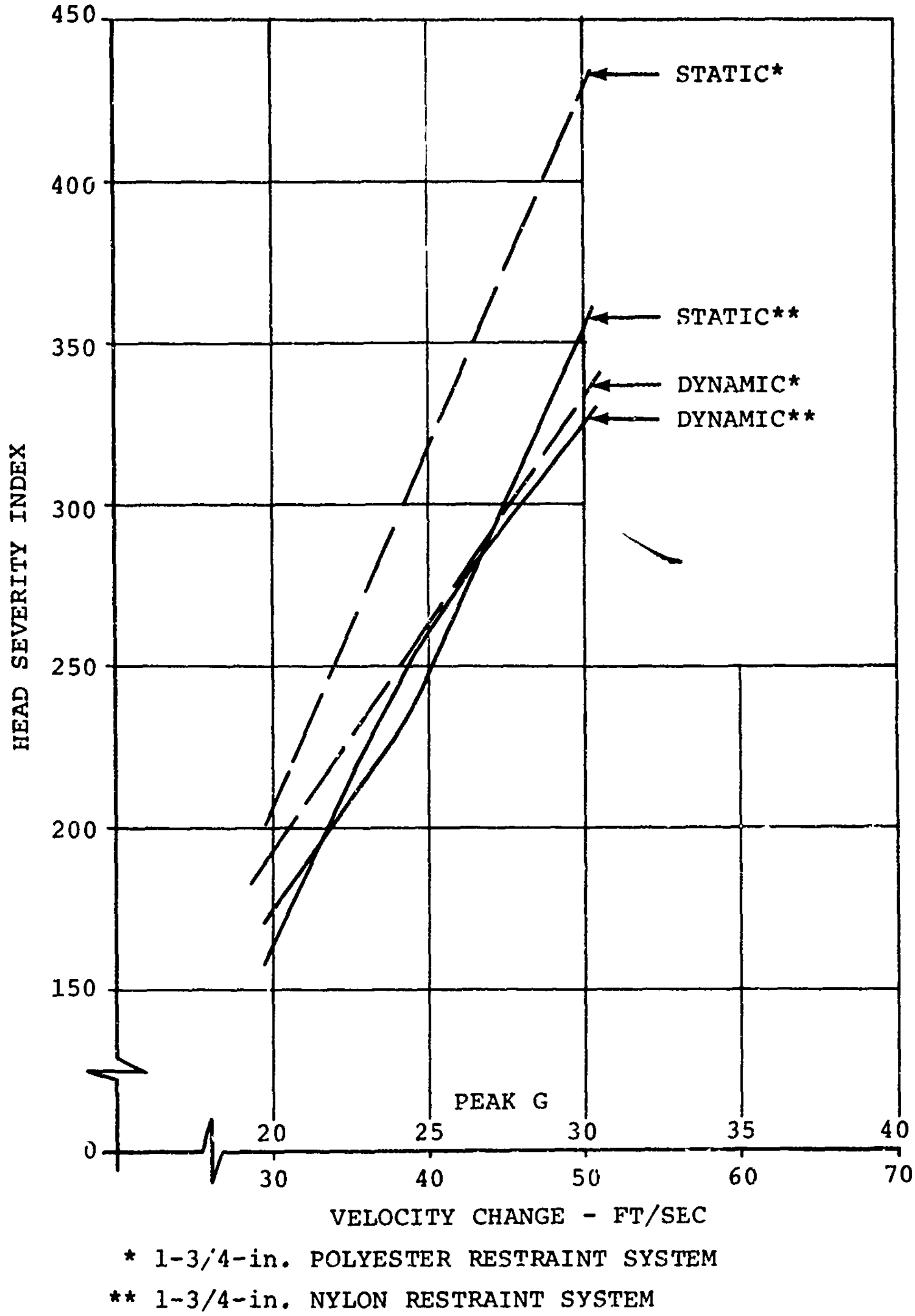


Figure 37. The Effect of Static Versus Dynamic Webbing Properties on the Severity Index for the Head of a 95th Percentile Occupant With Full Gear Under Various Triangular Input Pulses.

Maximum loads obtained for nylon shoulder harnesses were generally larger when dynamic properties were used. Both nylon and polyester lap belts, as well as polyester shoulder harnesses, exhibited larger loads for the static webbing properties. The restraint system loads calculated with dynamic webbing properties were generally within 20 percent of those calculated using static webbing properties, however.

The data did indicate that results obtained using static webbing properties as a general rule were more severe than those obtained using dynamic webbing properties. Thus, if restraint systems were designed upon the basis of the static webbing properties, the design would normally be slightly conservative.

Effect of Material Stiffness

Figures 38 and 39 represent some of the results of the analysis of the material stiffness effect. Figure 38 is for the high-energy crash pulse (ΔV = 50 ft/sec, G_p = 30), while Figure 39 is for the low-energy pulse (ΔV = 30 ft/sec, G_p = 20). The data shown in both figures are for the 95th percentile occupant equipped with helmet, body armor, and vest-type survival kit subjected to a longitudinal crash pulse. The plots in all figures are the head severity index versus material stiffness. To simplify the discussion, the material stiffness has been replaced by the associated width of the shoulder harness webbing.

Harness webbing widths are shown on the abscissa, while values for the head severity index are shown on the ordinate.

Both figures indicate that, from a head severity index standpoint, it is dangerous to combine a stiff lap belt with a less stiff shoulder harness. A severity index of 970 was obtained for a 1-3/4-inch polyester lap belt combined with a 1-3/4-inch nylon shoulder harness under the high energy pulse. A head severity index of 1000 is considered dangerous to life.

The figures show that there is essentially no difference between the behavior of 1-3/4- and 3-inch-wide polyester lap belts. The load-deflection relationships were approximately the same for the two belt widths, except that the 3-inch belt had a higher failure load.

The general trend of the data is that the stiffer the material used for the restraint system, the lower the value for the severity index. Thus, for a given input pulse, the occupant is less likely to be injured if he is restrained by a stiff restraint system. There might be a limit to this trend, depending on how stiff the material can be. This may be especially apparent in terms of high lap-belt and shoulder-harness

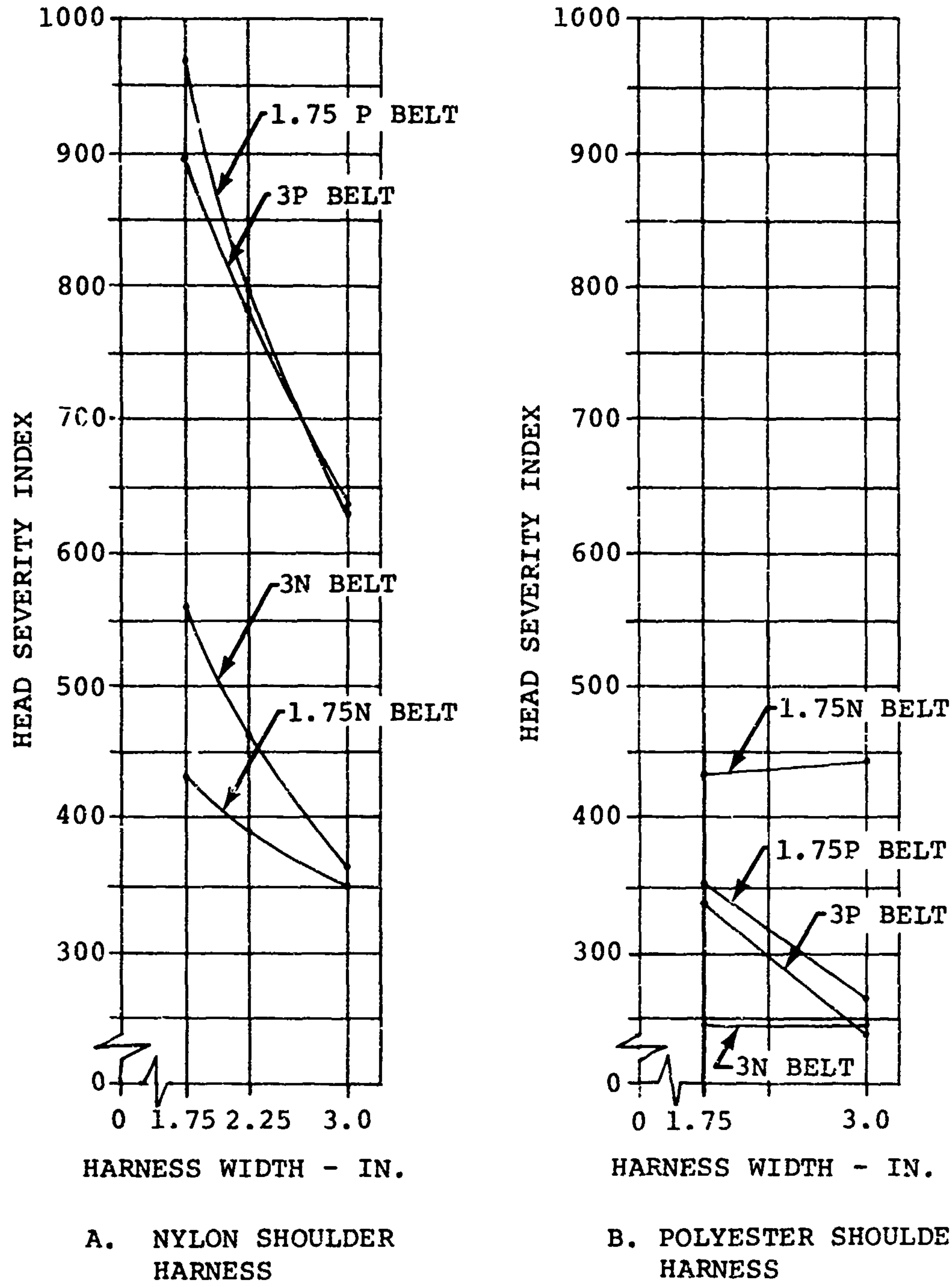
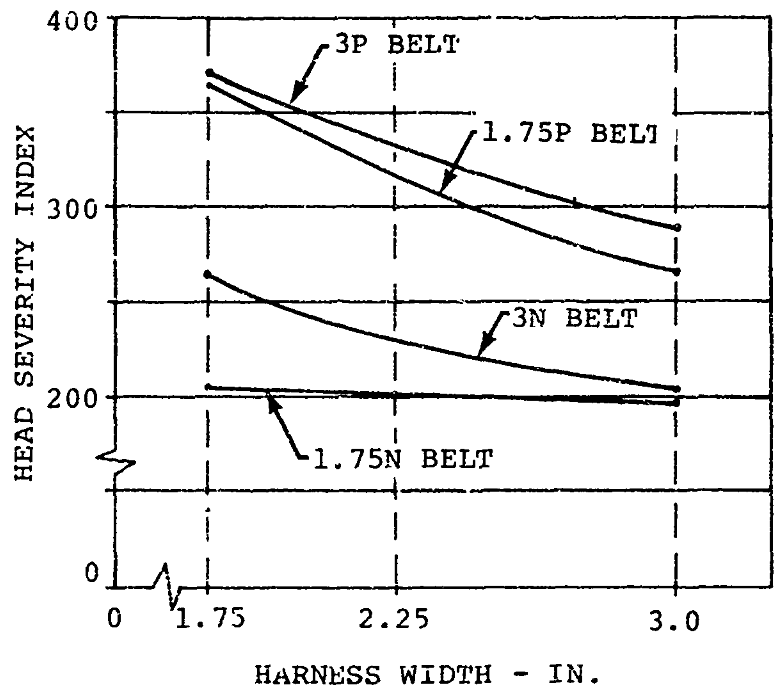
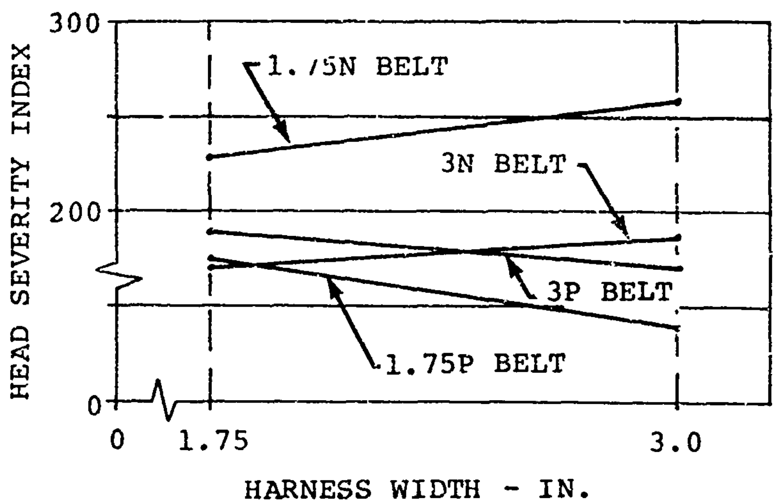


Figure 38. Head Severity Index Versus Material Stiffness, Longitudinal Crash Pulse ΔV = 50 ft/sec, G_p = 30 and 95th Percentile Occupant Equipped With Helmet, Body Armor, and Vest-Type Survival Kit.



A. NYLON SHOULDER HARNESS



B. POLYESTER SHOULDER HARNESS

Figure 39. Head Severity Index Versus Material Stiffness, Longitudinal Crash Pulse ΔV = 30 ft/sec, G_p = 20 and 95th Percentile Occupant Equipped With Helmet, Body Armor, and Vest-Type Survival Kit.

loads exerted on the occupants. For the nylon and polyester harness simulated in this study, however, the loads were comparable; deflections in the less stiff nylon webbings were on the order of two to three times those determined for the polyester belts.

Just as the head severity index will be higher if a less stiff shoulder harness is combined with a stiff lap belt, the severity index for the pelvis will be higher if a stiff shoulder harness is used with a less stiff lap belt. For example, a restraint system using a nylon lap belt and a polyester shoulder harness gave a pelvic severity index of 1100, while a restraint system having a polyester lap belt and a nylon shoulder harness yielded a pelvic severity index of only 572. In both cases, all webbings were 1-3/4-inch wide and the high-energy pulse (ΔV = 50 ft/sec, G_p = 30) was used. The value of 1100 determined for the pelvic severity index has not been definitely related to an injury probability, but it is obvious that the restraint system used was nearly twice as harmful as when the webbing materials were reversed.

A general rule, then, is that the restraint system should consist of a lap belt and shoulder harness having essentially the same material stiffness. As measured by the severity index, a stiffer material will cause the probability of injury to decrease and will also decrease the deflections in the restraint system. Less deflection in the restraint system means less springback in the system and less chance of the occupant developing a high velocity to impact the seat on rebound.

For the high-energy pulse, the lowest head severity index resulted for a restraint system in which both lap belt and harness were made of 3-inch polyester webbings. This combination also gave the lowest values for chest and pelvic severity indexes. This was the stiffest restraint system used in the comparisons.

Effect of Occupant Size

For the high-energy pulse (ΔV = 50 ft/sec, G_p = 30), the pelvic, chest, and head severity indexes decreased as the weight of the occupant increased for most cases in which the lap belt and shoulder harness were made of the same material. A similar trend was evident for the lower-energy pulse. When the lap belt was made of a 3-inch nylon webbing and the shoulder harness was made of 3-inch polyester webbing, the severity indexes increased with occupant weight for the high-energy pulse and decreased with increasing occupant weight for the lower-energy pulse (see Table XVIII).

TABLE XVIII. EFFECT OF OCCUPANT SIZE ON SEVERITY INDEX FOR VARIOUS RESTRAINT SYSTEMS AND CRASH PULSES

Restraint System		Severity Index									Pulse	
		Pelvis			Chest			Head				
Belt	Harness	5% Occupant	50% Occupant	95% Occupant	5% Occupant	50% Occupant	95% Occupant	5% Occupant	50% Occupant	95% Occupant	ΔV (fps)	G_p (G)
1-3/4-Inch Nylon	1-3/4-Inch Nylon	734	722	618	491	461	396	488	554	429	50	30
		348	306	289	285	217	205	310	237	205	30	20
3-Inch Nylon	3-Inch Polyester	299	427	428	205	280	308	207	232	243	50	30
		333	291	239	243	199	173	238	198	188	30	20
3-Inch Polyester	3-Inch Polyester	547	358	285	406	257	203	387	296	239	50	30
		244	208	208	191	255	156	181	165	171	30	20

Note: The 50th and 95th percentile occupant weights include the weight of a helmet, survival vest, and body armor. The 5th percentile occupant has no body armor.

The stiffer 3-inch polyester restraint system gave severity indexes nearly twice as high for the 5th percentile occupant as for the 95th percentile occupant under the high-energy pulse. The differences were not as marked for the low-energy pulse with the polyester system, or for either pulse with the 1-3/4-inch nylon restraint system. Figure 40 shows the variation of head severity index for the two restraint systems under the various pulse magnitudes as a function of occupant size.

The occupant size analysis leads to the conclusion that, although the stiffer restraint system imposes nearly twice as high head severity indexes on the smallest occupant as on the largest occupant, the 5th percentile occupant with the stiff polyester restraint system is still better off than the 95th percentile occupant with the weaker nylon restraint system.

Effect of Restraint System Slack

Table XIX indicates the effect of slack in the restraint system upon the severity indexes for the head, chest, and pelvis for a particular occupant and input pulse. The occupant was a 95th percentile male with helmet, survival vest, and body armor. The pulse was a high-energy (95th percentile peak G and velocity change) pulse with ΔV = 50 ft/sec and G_p = 30. Increasing belt slack from 0 to 3 inches for a constant shoulder harness slack of 0.25 inch approximately doubled the pelvic severity index for the weaker nylon restraint system; but for the stiffer polyester restraint system, the pelvic severity index was approximately 4 times as large for the 3-inch slack as for no slack in the belt. The pelvic severity index for

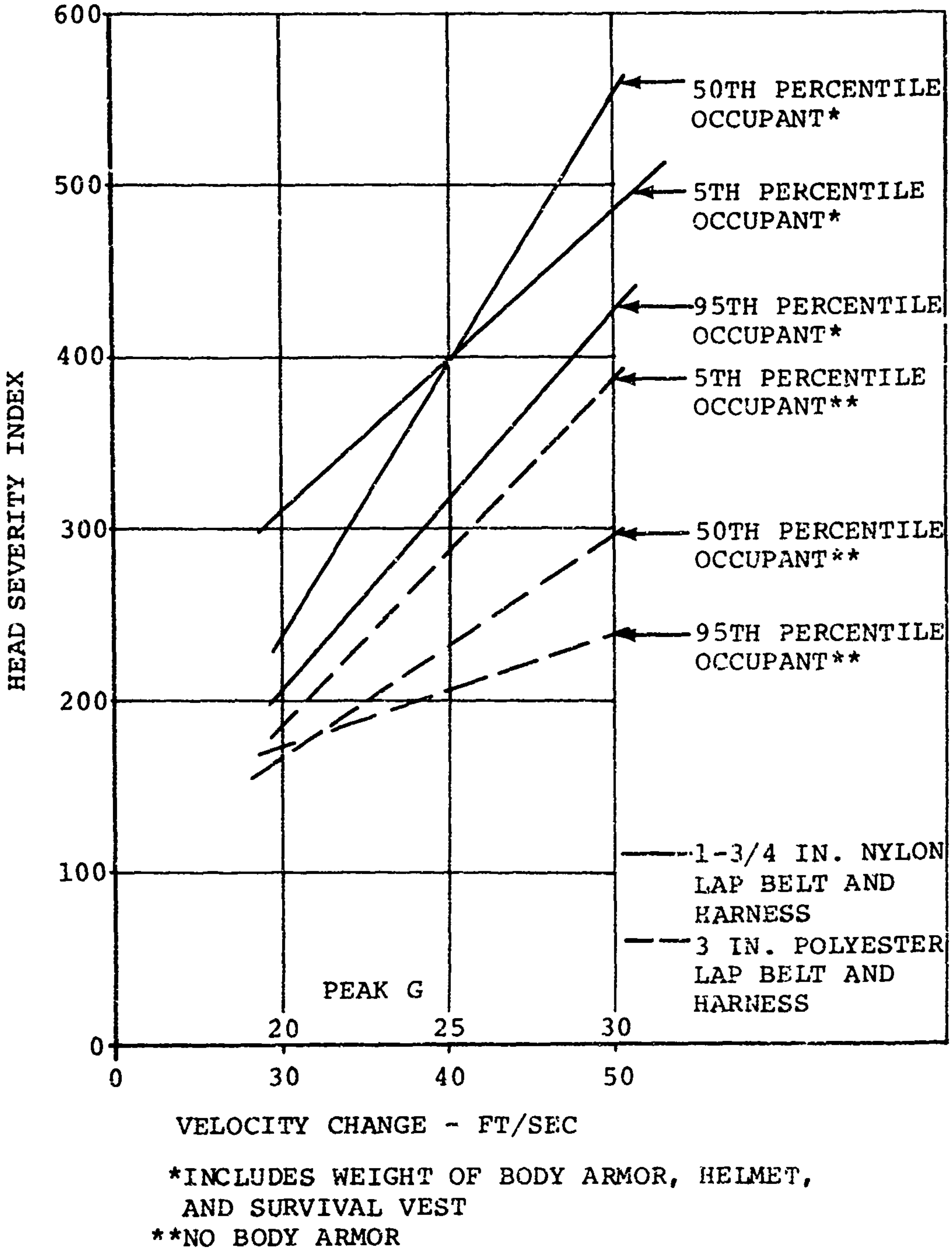


Figure 40. Effect of Occupant Size on the Head Severity Index for Two Restraint Harnesses Under Various Pulses.

TABLE XIX. THE EFFECT OF RESTRAINT SYSTEM SLACK UPON SEVERITY INDEXES FOR A 95TH PERCENTILE OCCUPANT WITH FULL GEAR IN A HIGH ENERGY (ΔV = 50 FT/SEC, G_p = 30) CRASH PULSE

Restraint System		Severity Indexes			Slack	
Belt	Harness	Pelvis	Chest	Head	Harness	Belt
3-Inch Poly-ester	3-Inch Poly-ester	285	203	239	.25	0
		663	397	294		1
		783	485	332		2
		1294	758	580		3
		675	468	334	1	2
		587	420	342	2	
1-3/4-Inch Nylon	1-3/4-Inch Nylon	618	396	429	.25	0
		710	438	394		1
		902	531	415		2
		1159	649	476		3
		1006	620	517	1	2
		904	610	579	2	

3-inch slack in the stiff lap belt was even greater than the severity index for the same slack in the weaker lap belt.

For a 2-inch slack in the lap belt, a variation in shoulder-harness slack from 0.25 to 2 inches did not seem to make much difference in the head severity index for the stiffer polyester restraint system. It increased the head severity in the nylon restraint system, however, from 415 to 579. The pelvic severity index decreased as the harness slack increased for a 2-inch belt slack in the polyester restraint system but did not vary consistently for the nylon restraint system under the same conditions.

The results of this analysis indicate that as little slack as possible is desirable for restraint systems. The increase in lap-belt slack is less dangerous for a weaker restraint system than it is for a stiffer one, however.

The Effect of a Powered Inertia Reel

The effect of a powered inertia reel was simulated by introducing a preload into the shoulder harness. The results are indicated in Table XX for a 3-inch polyester belt and harness restraint system. The table gives severity indexes for the pelvis, chest, and head of a fully equipped 95th percentile occupant. The differences between the baseline runs (no preload) and the powered inertia reel runs (harness preload) in all cases amounted to less than 10 percent for the pelvic severity index and less than 3 percent for the head and chest severity indexes. Belt and harness loads for the cases in Table XX did not differ by more than 3 percent with and without preload.

TABLE XX. THE EFFECT OF A HARNESS PRELOAD UPON SEVERITY INDEXES AND MAXIMUM RESTRAINT LOADS FOR A 95TH PERCENTILE OCCUPANT WITH FULL GEAR RESTRAINED BY A 3-INCH POLYESTER RESTRAINT SYSTEM

Harness Preload (lb)	Input Pulse		Severity Indexes			Maximum Belt Load (lb)	Maximum Harness Load (lb)
	ΔV (fps)	G_p (G)	Pelvis	Chest	Head		
0	50	30	285	203	239	5977	4683
300	50	30	312	209	241	5936	4626
0	30	20	208	156	171	3335	3045
200	30	20	223	159	165	3427	3011

For the high-energy pulse, the preload of 300 pounds increased the severity indexes for the pelvis, chest, and head. For the low-energy pulse, the preload of 200 pounds increased the severity indexes for the pelvis and chest but decreased the head severity index.

Analysis indicates that adding a powered inertia reel or increasing tension beyond elimination of slack has little effect upon the performance of the restraint system.

Energy-Absorbing Webbings

Energy-absorbing webbing (B-type) having an elastic-plastic force-versus-elongation characteristic was compared to the

stiffest and least stiff of the standard webbings analyzed in the initial series of runs. The results of this comparison are contained in Table XXI. The load-deformation characteristics of the B-type energy-absorbing webbing are shown in Figure 41.

TABLE XXI. COMPARISON OF ENERGY-ABSORBING WEBBING WITH NYLON AND POLYESTER WEBBINGS FOR A 95TH PERCENTILE OCCUPANT WITH FULL EQUIPMENT

Restraint System		Severity Index			Pulse	
Belt	Harness	Pelvis	Chest	Head	ΔV (fps)	G_p (G)
EA (B-Type)	EA (B-Type)	152	123	110	50	30
		116	90	85	30	20
	3-Inch Polyester	252	69	711	50	30
		162	114	240	30	20
3-Inch Polyester	EA (B-Type)	464	212	461	50	30
		217	124	151	30	20
EA (B-Type)	1-3/4-Inch Nylon	354	165	574	50	30
		73	103	243	30	20
1-3/4-Inch Nylon	EA (B-Type)	851	346	628	50	30
		302	155	104	30	20
3-Inch Polyester	3-Inch Polyester	285	203	239	50	30
		208	156	171	30	20
1-3/4-Inch Nylon	1-3/4-Inch Nylon	618	396	429	50	30
		289	205	205	30	20

The results show that, from a severity index standpoint, the 95th percentile occupant with full equipment would be much better off with a full energy-absorbing restraint system. The head severity index for the energy-absorbing restraint system

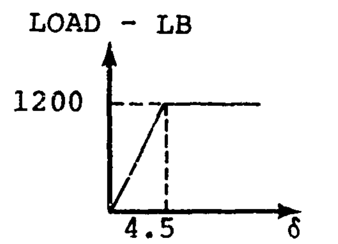


Figure 41. Load/Elongation Characteristics Assumed for the B-Type Energy-Absorbing Webbing.

in the high-energy pulse was only 110 compared to the 239 obtained for the same pulse and a 3-inch polyester restraint system. The loads in both belt and harness were limited to 1200 pounds in the energy-absorbing system, while belt loads were about 6000 pounds and harness loads over 4500 pounds in the 3-inch polyester system. The problem, however, is that deflections in the energy-absorbing system are 4 to 6 times as large as they are in the standard polyester system. This would result in a much greater probability of strike-zone type injuries for the energy-absorbing system.

The effects of mixing materials in the restraint system noted in the initial nylon-polyester runs were again evident when these materials were combined with the B-type energy-absorbing webbing. For example, the stiff polyester webbing used as a shoulder harness in combination with the B-type energy-absorbing lap belt resulted in a head severity index over 6 times as high as that for the full energy-absorbing system in the high-energy crash pulse. When the belt was made of a 3-inch polyester webbing and the harness was made of the energy-absorbing material, the resulting head severity index for the high-energy pulse was over 4 times as high as for the full energy-absorbing system. The results were not as marked when the energy-absorbing belts were combined with the 1-3/4-inch nylon belts.

Indications are that a full energy-absorbing restraint system would be advantageous if there were sufficient room available for it to stroke without the occupant hitting anything.

<u>Input Pulse Shape</u>

Three variations of a triangular pulse with a constant velocity change and peak accelerations were tried in an effort to

determine the effect of the input pulse shape upon the severity indexes for the occupant, which in this case was a 5th percentile male with helmet and survival vest. In the three runs the peak was applied at the 5th, 50th, and 95th percentile points of the basic time base. The basic variable is the rate of onset of the loading. Results of the analysis are shown in Table XXII; t_1 and t_2 are defined in Figure 42. The restraint system was composed of a 3-inch polyester belt and harness. The velocity change was 50 ft/sec and the peak acceleration was 30G.

TABLE XXII. VARIATION IN SEVERITY INDEX WITH INPUT PULSE SHAPE FOR A 5TH PERCENTILE OCCUPANT WITH HELMET AND SURVIVAL VEST IN A HIGH ENERGY TRIANGULAR PULSE (ΔV = 50 FT/SEC, G_p = 30)

t_1	t_2	Severity Index		
		Pelvis	Chest	Head
.00518	.1036	870	762	878
.05180	.1036	547	406	387
.09840	.1036	200	172	192

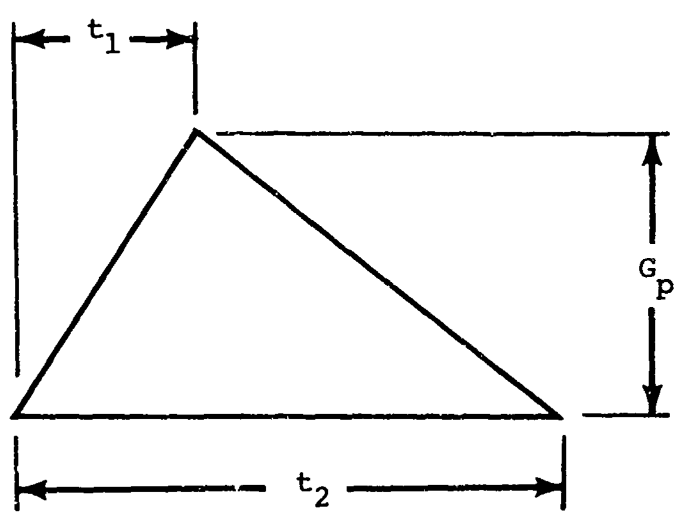


Figure 42. Definition of Input Pulse Shape Variables.

The analysis showed that the severity indexes varied nearly linearly with the rate of onset of loading for the 3 pulses. The high rate of onset caused severity indexes over 4 times as great as the low rate of onset of the load.

Final Restraint System Analyses

The decision to use polyester for all the webbing components was based upon the results of the webbing trade-off. Polyester webbing complying with MIL-W-25361 except for weave pattern was specified for the restraint system.

The static tests of the webbings indicated that the best pressure distribution for the belts was obtained with a 2-1/4-inch width. This width was chosen for the lap belt of the final system. Since no cases had been run with a 2-1/4-inch polyester webbing, a final series was run. To further justify the one-material system, runs were also made for two different shoulder harness configurations. In all cases the force-deflection characteristics of a 2-1/4-inch-wide polyester webbing were used for the lap belt. For the first three cases, the same properties were used for the shoulder harness. These analytical choices were made because at this time it had been decided to use 2-1/4-inch-wide webbing for the lap belt and possibly for the shoulder straps. Because of the use of the horse collar with load-spreader backup padding eventually chosen for the selected restraint system concept, the use of 2-1/4-inch-wide webbing for the shoulder straps was not necessary and was eliminated from consideration. The linear force-deflection properties of the A-type polyester load-limiting webbing (see Figure 43) were used in the fourth, fifth, and sixth cases. The force-deflection characteristics of the previously described B-type energy-absorbing webbing were used in the last three cases.

The crash pulse shape used in the analysis was triangular, and three cases were run for each of the three restraint systems. The velocity change (ΔV) and the peak deceleration (G_p) of the input pulse were different for each case, although the shape of the crash pulse was the same for all the cases. This was done so that the effect of the severity of the crash pulse could be evaluated together with the webbing effect. The results of this analysis are tabulated in Table XXIII.

The exact webbing configuration to be used with the selected concept was not run; however, it is anticipated that differences would be insignificant as there is in general no difference in the initial shape of the force-deflection characteristics of the webbing.

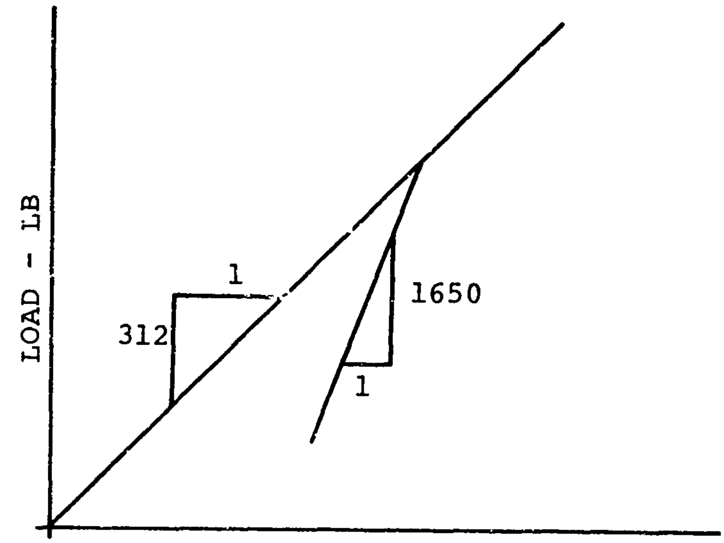


Figure 43. Load/Elongation Characteristics for A-Type Energy-Absorbing Webbing.

TABLE XXIII. SUMMARY OF FINAL RESTRAINT SYSTEM ANALYSES

Case	Type Harness Material	Severity Index			Deflection (in.)		Force (lb)		Pulse (Δ)	
		Pelvis	Chest	Head	Belt	Harness	Belt	Harness	ΔV (ft/sec)	Peak G (G)
1	2-1/4 P	346	224	281	3.57	3.68	6139	4600	50	30
2	2-1/4 P	304	198	212	3.23	3.02	5.26	3765	40	25
3	2-1/4 P	164	130	137	2.76	2.48	3751	3079	30	20
4	A	552	387	881	3.54	14.00	6052	4383	50	30
5	A	345	220	532	3.21	11.30	5060	3515	40	25
6	A	234	142	296	2.79	8.53	3823	2661	30	20
7	B	502	206	443	3.66	22.90	6395	1200	50	30
8	B	332	137	223	3.31	15.30	5370	1200	40	25
9	B	310	155	169	2.87	7.50	4071	1200	30	20

The force-deflection characteristics of a 2-1/4-inch polyester belt were used in all cases. A 95th percentile Army aviator with helmet, armor vest, and survival kit (vest type) was used in all cases.

The principal advantages of an enerby-absorbing type of webbing are: (1) reducing the maximum load that the webbing exerts on the occupant and (2) reducing the amount of energy stored in the webbing. Both can be evaluated either analytically or through testing; therefore, the analysis was made. The second item is really concerned with the rebound velocity of the occupant. In the present state of the art, this can most accurately be determined through testing and analysis of dummy kinematics through the use of high-speed film.

Comparing the results of the system using the A-type load-limiting webbing to the system using the 2-1/4-inch-wide polyester webbing for the shoulder straps, it is seen that the load-limiting webbing helps somewhat to reduce the loads to the occupant. This is true except for the case of the mild pulse where the lap-belt load is increased. Both the shoulder harness deflection and the severity index are increased when the A-type webbing is used for a shoulder harness. In particular, the head severity index for the severe pulse is approaching the danger area of 1000. The increases in the shoulder harness deflection and especially of the head severity index are not considered to be a good compromise for the rather small decrease in occupant loads. Therefore, this type of webbing does not present any special advantages as compared to the standard polyester webbing.

Comparing the results of the system using the B-type energy-absorbing webbing to the polyester system, it is seen that lap-belt loads, deflections, and severity index increase with the exception of the chest severity index for the severe and medium pulses. The webbing performed well with a low constant shoulder-strap load of 1200 pounds. The increase of the lap-belt deflections is insignificant, and the increase in lap-belt loads is not severe. The increase of the pelvic, chest, and head severity indexes is also well within tolerance limits. However, the shoulder harness deflection of almost 23 inches for the severe pulse is unacceptable.

RESTRAINT SYSTEM DEVELOPMENT

INTRODUCTION

The literature search and the variables analysis provided information vital to the choice of restraint system variables; however, some questions were still unanswered. These included the effect of lap-belt webbing width on applied pressure, the choice of a material weave pattern and restraint system configuration, and, finally, whether or not to use a powered inertia reel.

PASSIVE RESTRAINT VERSUS ACTIVE RESTRAINT

One question resolved very early in the program was whether the optimum aircrew restraint system to be developed would be of the passive type (air bags) or the active type (lap-belt/shoulder-straps combination). Although there was a "feel" that the combination lap-belt/shoulder-harness system would provide the best restraint for this particular application, the possibility of using a passive restraint system could not be ignored without justification.

The principal advantage of the air bag system is that it provides maximum area for spreading body loads. Disadvantages are many.

First, a high level of sound is produced during the deployment. This level is high enough (140 to 178 decibels) to cause concern over hearing damage to exposed individuals. Research conducted by the National Highway Traffic Safety Administration at Wright Field indicates that there is no serious problem associated with the sound resulting from deployment of a single system since there was no permanent impairment of the hearing of test subjects. Greater concern has been expressed over the result of the deployment of multiple bags in a single enclosure on the assumption that the pressures are accumulative.

Another major problem area is that of reliability, i.e., relying on the system to deploy when required and not deploy inadvertently. The problem of the long-term reliability (5 years) of all the components in the vehicle environment is frequently expressed. Aging of the bag material leading to bag failure is an example.

Another area of concern is the maintainability and inspectability of the systems. Since maintenance of this equipment installed in vehicles is very difficult, systems would have to be designed and built for minimum maintenance. From an inspectability point of view, good nondestructive tests of the total

system are not available. Partial system checks and tests of the electrical circuitry, for example, could be made; however, this again points up the need for a highly reliable system.

The inflatable restraint systems using a cylinder of very high-pressure gas pose a safety hazard associated with potential rupture. On the other hand, those systems based on generating the gas from a pyrotechnic pose a temperature problem. The outside surface temperature of the bag may become high enough to burn an occupant, and the hot gas itself would produce trauma in the event of bag rupture during the deployment process.

The most severe criticism of the air-bag systems for aircraft application is that they are directional in their protective properties, providing no protection in other than frontal crashes unless several systems are installed. Also, at least a lap belt would be required to provide restraint during maneuver loading and to keep the occupant in place during secondary impact.

Based on these considerations, passive restraints were eliminated from further consideration.

STATIC TESTS TO INVESTIGATE THE EFFECT OF LAP-BELT WIDTH ON PRESSURE

Background

Selection of the optimum webbing width for a lap belt and shoulder harness must be based on two conflicting requirements: (1) maximum width for lowest pressure and (2) minimum width for maximum comfort and minimum hardware weight. The minimum width of the lap belt for a forward-facing seat is specified in the Design Guide[8] to be 2-1/2 inches, with a desirable greater width (up to 4 inches) in the center abdominal area. However, none of the armed forces are using a 2-1/2-inch-wide lap belt at the present time. Typical lap-belt widths presently used include 1-3/4 inches for passenger troop restraint (Army, Navy, Air Force); 1-3/4 inches for pilot restraint (Air Force); and 3 inches for pilot restraint (Army, Navy, Air Force). Since the narrow webbing without load-spread backup plates might not provide adequate load distribution and support, a test program to investigate this variable was performed.

Method for Measuring the Pressure

Several techniques for measuring the pressure between the lap belt and the dummy were investigated, including the crushable material technique. Rough calculations indicated very high

pressure on and around the pelvic bone area. As a result, a high density crushable material was needed in order to get data in this area. However, from the samples available, higher density meant stiffer material. For the high pressures calculated, the material would have been too stiff to react realistically; therefore, this technique was discarded. Some of the other techniques were rejected for similar reasons, while others required extensive development and/or complex test setups.

It was finally decided to use a series of biomedical subminiature transducers. These transducers are used for a variety of medical applications involving fluid pressure. They have a unitized construction diaphragm machined from one piece of material. The diaphragm, although thin for sensing low pressures, is relatively rugged. The load cell can be thought of as a fluid pressure transducer that is calibrated to measure force or weight directly. The force or weight is distributed uniformly over the entire diaphragm surface by a special loading button or by using an incompressible medium such as silicon rubber.

The model selected for this application has a circular housing approximately 0.040 inch thick and 0.25 inch in diameter. The diaphragm is round and has an effective area of approximately 0.03 inch^2 and a force range of 0 to 100 pounds. This means that it can measure pressures in excess of 3000 psi at full scale. The accuracy is 2 to 3 percent. At full scale, it has 1-mv-per-volt output-to-input ratio.

Test Objective

The objective of these static tests was to define the tradeoff between belt width and lap-belt pressure distribution.

Description of Test Article

The test articles were eight types of nylon and polyester webbings described in MIL-W-4088F and MIL-W-25361B, respectively. The particular types tested are shown in Table XXIV.

Types IX and XXVII nylon were used to check out and establish the procedure for the test, since these two types are close to the extreme lap-belt widths that were available. Types I, III, and V of the polyester webbing are of different thickness while essentially of the same width. These three types were selected so the effect of webbing thickness would also be obtained.

TABLE XXIV. WEBBINGS USED FOR THE BELT WIDTH VERSUS LAP-BELT PRESSURE DISTRIBUTION STATIC TESTS			
Type	Nominal Width (in.)	Nominal Thickness (in.)	Tensile Strength (lb)
Nylon, MIL-W-4088F			
XXV	1-1/4	.070	4500
XXVII	1-23/32	.094	8000
XXVIII	2-1/4	.095	8700
IX	3	.0825	9000
Polyester, MIL-W-25361B			
IV	3	.077	8700
III	1-23/32	.085	7000
V	1-3/4	.120	10000
I	1-23/32	.0525	3600

Calibration of Subminiature Transducers

The factory calibration of the pressure-measuring cells was checked with the setup shown in Figure 44. A set of laboratory weights was used for this purpose.

The cell was first checked on a level rigid surface in a manner similar to the way the transducer was calibrated at the factory. Then the cell was checked on an uneven soft surface and the load was applied in a way that more closely approximated the particular test application. This latter check was made to determine whether the manner of load application on the cell would affect the cell calibration.

Test Preparation

The complete test setup was mounted on an appropriate surface (see Figure 45). The seat used was a single-passenger, high-strength fixture type that weighs approximately 90 pounds. Small triangular plates were placed on each side of the seat where the lap-belt anchor attachments would normally be so that the lap belt would rub on a smooth surface during testing. Raising the front end of the seat decreased the angle the lap belt makes with the seat pan, while raising the rear end of the seat increased this angle. This technique was used to

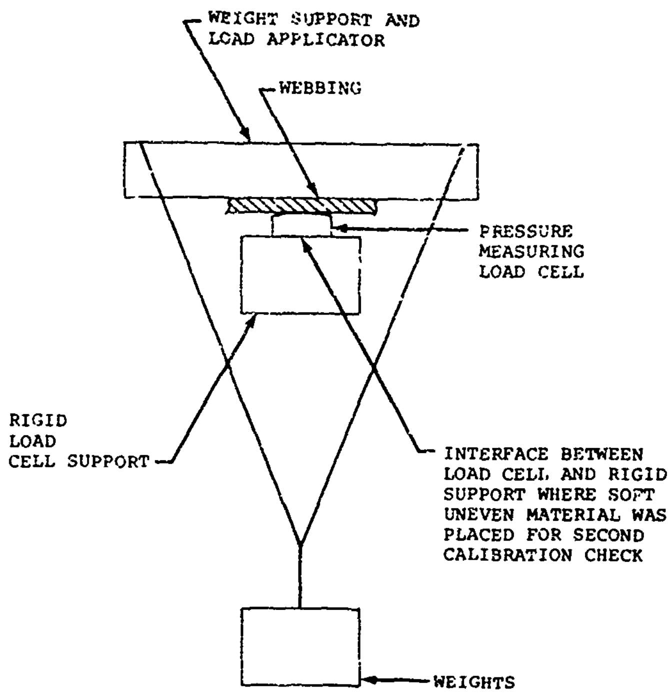


Figure 44. Calibration Setup for the Pressure-Measuring Subminiature Transducers.

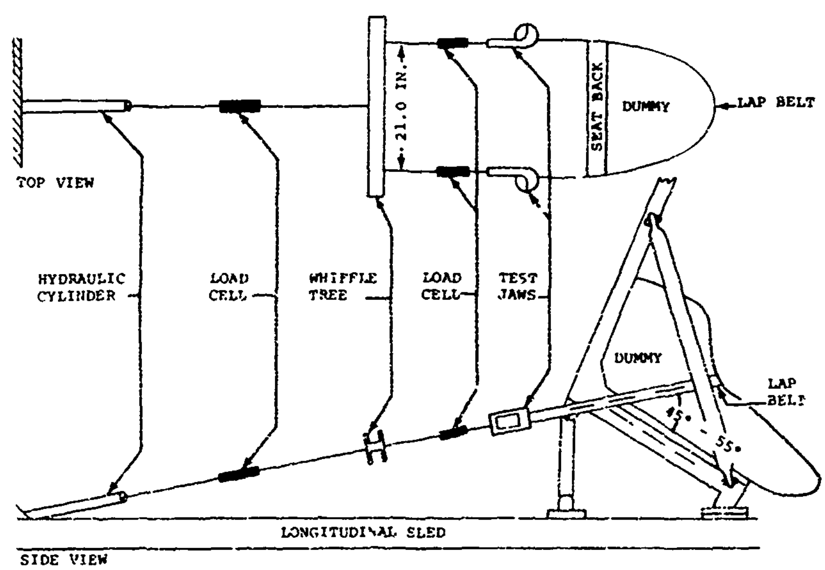


Figure 45. Test Setup.

adjust the lap-belt/seat-pan angle to 20 to 30 degrees and to 70 to 80 degrees for the applicable tests.

The body block was a portion of a 50th percentile male dummy. This dummy was selected for this evaluation because of its close simulation of the human abdominal region, particularly the pelvic bone and iliac crest. Only the pelvic assembly, the lower part of the thoracic flesh section with an adapter plate for retention, the foam-filled abdominal sac, and the molded upper leg assembly (right and left) were used.

The dummy was secured to the seat by a cap screw through the seat back into the dummy back. This screw restricted the forward and downward motion of the dummy due to gravity while it offered no resistance to the squeezing motion of the dummy against the seat.

A 1-inch-thick cushion was used between the dummy and the seat pan, and no cushion was used between the dummy and the back of the seat.

The maximum tensile load applied to the lap belt during testing was 4000 pounds.

Fatigue effects in webbings and fabrics have been found to be negligible at loads below 80 percent of original breaking strength. This meant that for the Type XXV nylon and Type I polyester, the webbing had to be replaced after every test. The other types of nylon as well as the polyester were well within safe limits; therefore, the same piece of webbing was used for all tests.

A 10000-pound load cell was installed between the hydraulic cylinder and the whiffletree to measure total load, and a 4000-pound cell was installed on each side to measure the individual belt loads.

For each test, the lap-belt webbing was placed around the buckle simulator (see Figure 46) so that the effects of the buckle assembly would be present. The webbing was gripped by jaws and the slack was taken from the system. The pressure-measuring load cells were placed between the dummy and the lap belt at the preselected locations. The test proceeded by application of loads in increments of 1000 pounds by use of a hydraulic cylinder. The pressure response was continuously recorded.

Pressure measurements were taken at three locations: (1) on top of the pelvic bone, (2) 1 inch forward (toward the face side of the dummy) from the pelvic bone, and (3) 1 inch back (toward the dummy backside) from the pelvic bone.

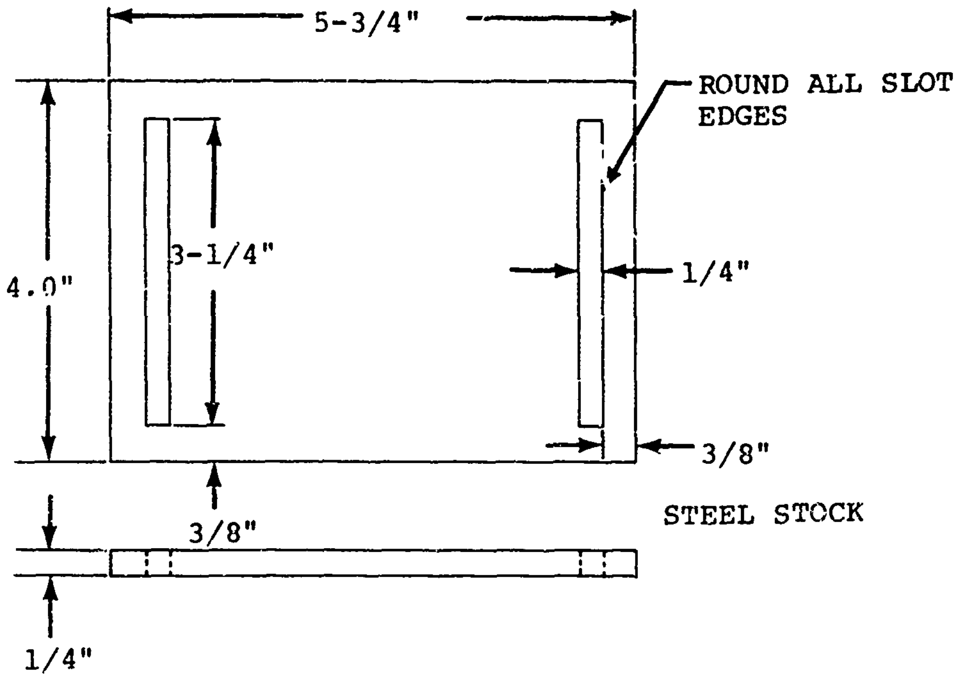


Figure 46. Lap-Belt Buckle Simulator.

Instrumentation Requirements

A total of three standard load cells and a maximum of eight subminiature transducers were used, depending on the size of the lap belt being tested. The type and the location of these load cells are tabulated in Table XXV.

TABLE XXV. INSTRUMENTATION EQUIPMENT

1.	Between Hydraulic Cylinder and Whiffletree	10000 lb (Tension)
2.	Between Whiffletree and Test Jaws (left side)	4000 lb (Tension)
3.	Between Whiffletree and Test Jaws (right side)	4000 lb (Tension)
4.	6 to 8 Subminiature Transducers Between Dummy and Lap Belt	100 lb each (Compression)

Load cells 1, 2, and 3 provided the force-time history of the load applied to the lap belt, while the subminiature transducers provided the pressure-time history between the dummy and the lap belt on top of the pelvic bone and at 1 inch on each side of the pelvic bone.

The forces measured by the standard load cells and the subminiature transducers used for each test were recorded on a direct-write oscillograph.

The pressure-measuring subminiature transducers were bonded on a 1-inch-wide Teflon tape. The gaps between the load cells were filled with silicon rubber sheet of 1/16-inch thickness. The load cells were arranged next to each other on a line along the width of the belt as shown in Figure 47. Two of these sets were made and used for all tests. All load cells were calibrated before installation in the test fixture.

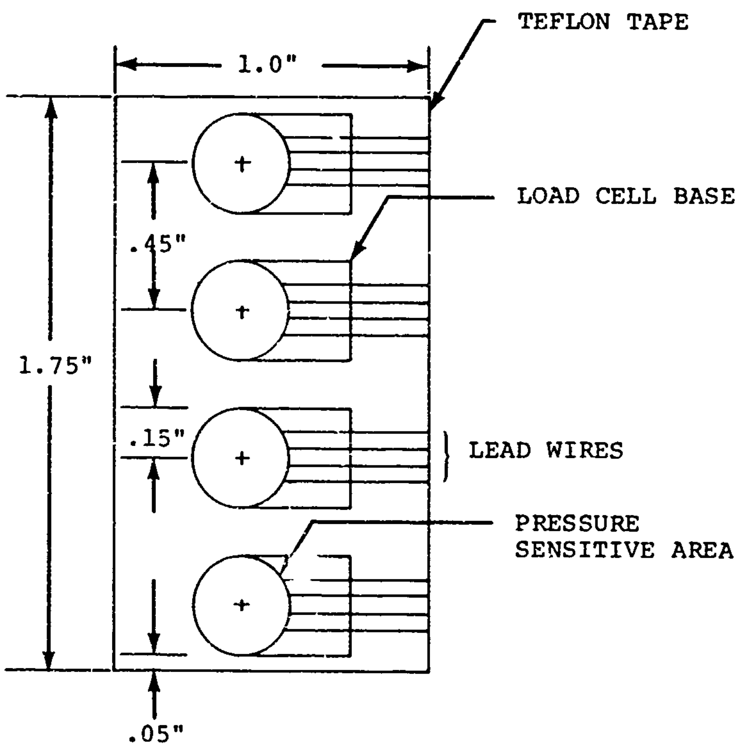


Figure 47. Arrangement of Pressure-Measuring Transducers.

Test Procedure

For each test, the lap-belt webbing was placed around the buckle simulator and gripped by webbing test jaws. The pressure-measuring load cells were placed between the dummy and the lap belt at the preselected locations. The slack was taken from the system. Load was applied in increments of 1000 pounds with a hydraulic cylinder. The tests run are summarized for each webbing width as follows:

1. 1-1/4-inch webbing tests (total of two)

   a. One set of data on top of the pelvic bone, the other set 1 inch forward from the pelvic bone.

   b. One set of data on top of the pelvic bone, the other set 1 inch backward from the pelvic bone.

2. 1-3/4-inch webbing tests of 4 types of webbing (total of eight)

   a. One set of data on top of the pelvic bone, the other set 1 inch forward from the pelvic bone.

   b. One set of data on top of the pelvic bone, the other set 1 inch backward from the pelvic bone.

3. 2-1/4-inch webbing tests (total of three)

   a. Two sets of data (end to end along the width of the belt) on top of the pelvic bone.

   b. Two sets (as in a.) 1 inch forward from the pelvic bone.

   c. Two sets (as in a.) 1 inch backward from the pelvic bone.

4. Three-inch webbing tests of two types of webbing (total of six)

   a. Two sets of data (end to end along the width of the webbing) on top of the pelvic bone.

   b. Two sets (as in a.) 1 inch forward from the pelvic bone.

   c. Two sets (as in a.) 1 inch backward from the pelvic bone.

This sequence completed all the tests planned for the 45- to 55-degree seat-belt/seat-pan angle.

The seat was then placed in a position that produced a lap-belt/seat angle of 70 to 80 degrees. The webbing that distributed the load the best in the previous tests (2-1/4-inch nylon) was used and three tests were run. The data were measured for the three locations previously described: on the pelvis, and 1 inch on each side of the pelvis iliac crest.

These three tests were repeated with a lap-belt angle of 20 to 30 degrees which completed the test series.

The total number of tests conducted to investigate the lap-belt width vers:s pressure was 25. They are tabulated in Table XXVI.

TABLE XXVI. TEST TABLE

Test No.	Type of Webbing	Location of Pressure Transducers: 1 Inch Backward	Pelvic Bone	1 Inch Forward
	Lap-Belt/Seat-Pan Angle 45° to 55°			
1	XXV Nylon		X	X
2	XXV New Test Piece	X	X	
3	XXVII Nylon		X	X
4	XXVII Same Test Piece	X	X	
5	III Dacron		X	X
6	III Same Test Piece	X	X	
7	V Dacron		X	X
8	V Same Test Piece	X	X	
9	I Dacron		X	X
10	I New Test Piece	X	X	
11	XXVIII Nylon		X	
12	XXVIII Same Test Piece			X
13	XXVII Same Test Piece	X		
14	XXV Nylon		X	
15	XXV Same Test Piece			X
16	XXV Same Test Piece	X		
17	IV Dacron		X	
18	IV Same Test Piece			X
19	IV Same Test Piece	X		
	Lap-Belt/Seat-Pan Angle 70° to 80°			
20	XXVIII Nylon		X	
21	XXVIII Nylon			X
22	XXVIII Nylon	X		
	Lap-Belt/Seat-Pan Angle 20° to 30°			
23	XXVIII Nylon		X	
24	XXVIII Nylon			X
25	XXVIII Nylon	X		

Photographic Requirements

Still photographs were taken before, during, and after the tests.

A real time movie was made during one of the tests for documentation purposes.

Test Results

All testing was performed as planned. However, a great portion of the data obtained was sporadic and inconsistent. Only the data felt to be pertinent are presented here.

Most of the data was obtained for the configuration in which the belt center line was at an angle of 45 to 55 degrees from the seat surface. The intersection of the belt and the seat surface was 2.5 inches forward of the seat reference point. Figure 45 shows the general setup.

On all the plotted data presented herein the pressure measurement on the ordinate is in psi while the abscissa represents the actual lap-belt width (ALBW). The longer vertical line on the abscissa indicates the center line of the lap belt. The shorter vertical lines indicate the relative locations of the load cells across the width of the belt during testing. The side of the belt toward the abdomen is shown on the abscissa closer to the zero point and is designated with the letter A. The side of the belt toward the legs is shown on the abscissa away from the zero point and is designated with the letter L. The small crosses on the plots indicate actual data points, and the line connecting two consecutive data points is solid. The dotted line reflects estimated profiles connecting data points when intermediate readings were missing or rejected because of anomalies.

Figure 48 shows the pressure distribution of the four types of nylon MIL-W-4088F webbings tested for a comparative pulling load of approximately 2000 pounds. It is immediately apparent that the part of the lap belt toward the legs carries the majority of the load. This supports the lap-belt installation instructions given in the Design Guide.[8] The results of these tests indicate that a lap belt installed according to these instructions will indeed tend to decrease the possibility of submarining.

Figure 48D shows the pressure distributions on the 1-1/4-inch webbing, Type XXV. Figure 49 shows that this webbing, although quite narrow, roped and forced an even smaller width of the webbing to carry the load. The narrow width and roping of the webbing produced the highest pressures of those measured.

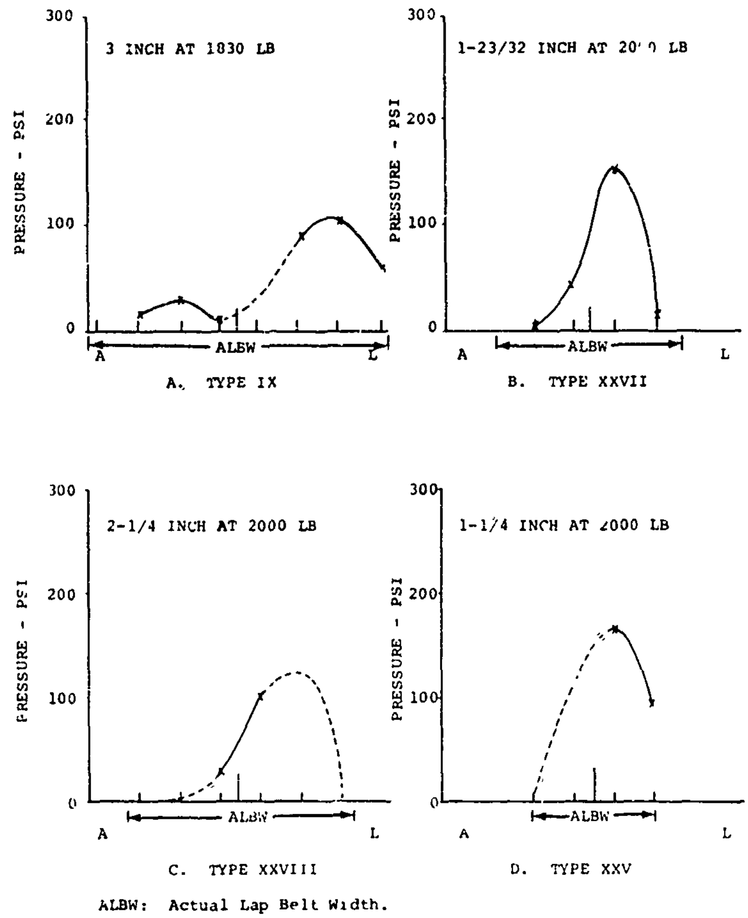


Figure 48. Nylon Webbings (Readings Taken on Pelvic Bone).

Figure 48B shows the pressure distribution for Type XXVII, 1-23/32-inch nylon webbing. Figure 50 shows that this webbing also roped. Comments made for the 1-1/4-inch webbing are valid for this webbing also, which is very similar to the webbing (Type XIII of MIL-W-4088) used for the HBU-2A/A automatic lap belt and which the Air Force is using to replace the MA-5 and MA-6 lap belts (3-inch-wide polyester webbing) on some types of ejection seats.

Figure 48A shows the pressure distribution for the 3-inch nylon webbing, Type IX. This webbing creased. An idea of how much creasing occurred can be gained by examining Figure 51, which shows the 3-inch polyester webbing at 2300 pounds pulling load. The 3-inch nylon and 3-inch polyester webbings behaved very similarly. The pressure distribution data for the 3-inch nylon webbing indicate that part of the webbing carried a very small load, resulting in a reduced effective width.

Figure 49. Type XXV Modified, 1-1/4-Inch Nylon Webbing at 2000 Pounds Pulling Load.

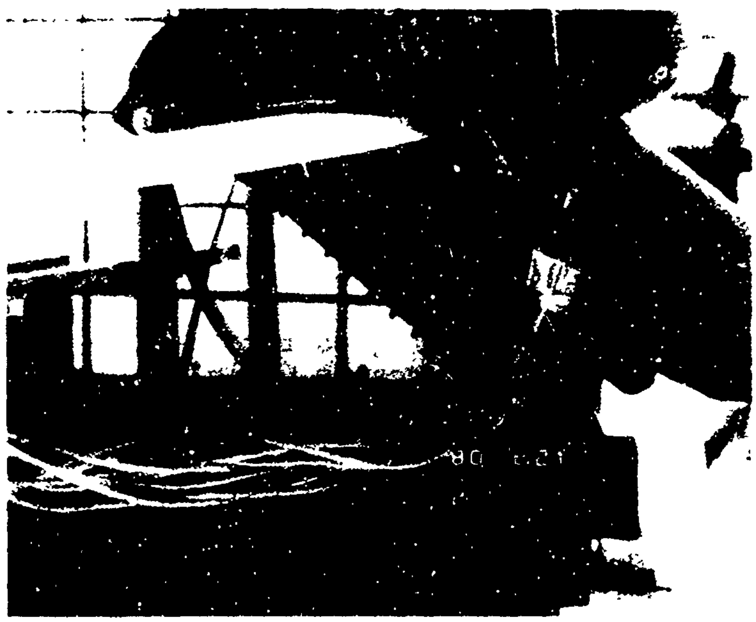


Figure 50. Type XXVII, 1-23/32-Inch Nylon Webbing at 2500 Pounds Pulling Load.

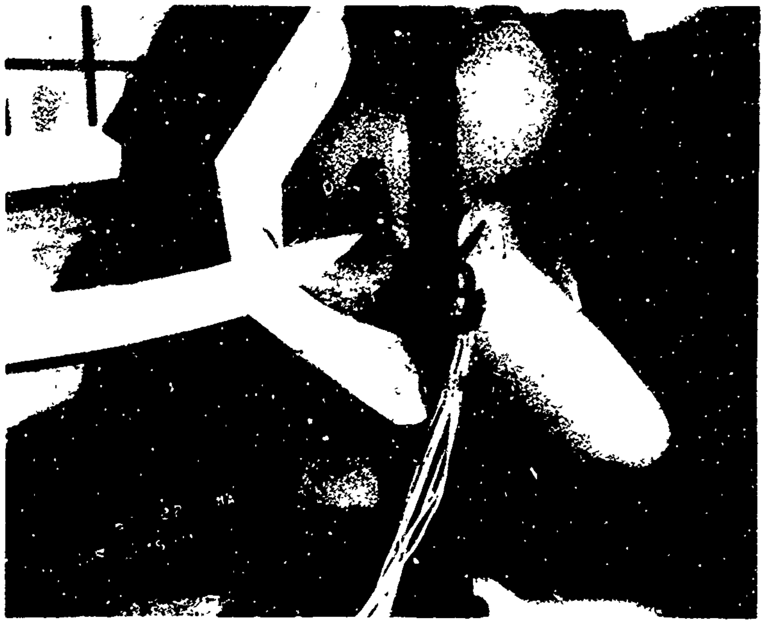


Figure 51. Type IV, 3-Inch Polyester Webbing at 2300 Pounds Pulling Load.

Finally, Figure 48C shows the pressure distribution from the 2-1/4-inch nylon webbing, Type XXVIII. Although the load cell that would have indicated the peak pressure (second load cell from the side of the webbing toward the legs) did not register readings, the curve shown is believed to be very close to reality. It was established by extrapolating the data at lower pulling loads as well as using the data from other locations (1 inch aft of the pelvic bone). Figure 52 shows that the 2-1/4-inch nylon webbing at 3000 pounds pulling load also creased.

The pressure distribution data for the 1-23/32-inch webbing indicate that the roping problem makes this webbing a poor choice. The data for the 3-inch webbing indicate that much of the width is ineffective and that the creasing permits the webbing to reduce its effective width. An optimum width is somewhere between these two widths. The data for the 2-1/4-inch webbing show a more continuous pressure distribution and indicate that this width would be a good choice.

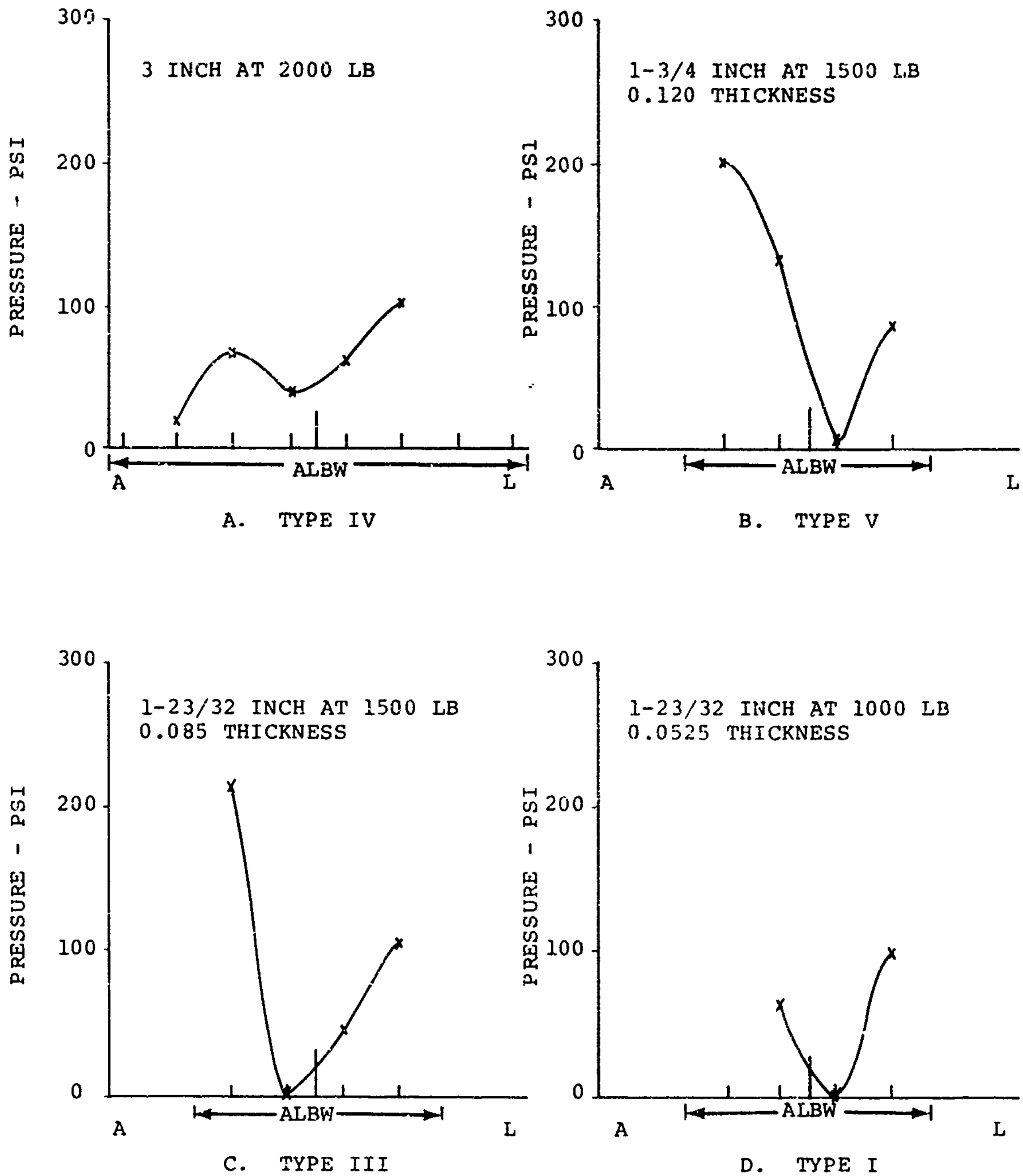
Figure 53 shows the pressure distribution data for the polyester MIL-W-25361B webbings tested. Figures 53B, 53C, 54, and 55, while referring to Types III and V, indicate that these

Figure 52. Type XXVIII, 2-1/4-Inch Nylon Webbing at 3000 Pounds Pulling Load.

two webbings behaved differently than the 1-23/32-inch nylon webbing; they did not rope. The high loads are shown on the abdomen side of the belt, which is not good from the standpoint of preventing submarining. It appears that the two sides of the webbing carried the loads independently. The weave pattern seemed to be influential in these differences, which indicated that, if polyester material were chosen for the optimum restraint system, the weave pattern should be comparable to that used in the nylon webbing. Also, the weave pattern of the nylon webbings tested has better abrasion characteristics than that used for the polyester webbings tested. This fact was verified by observation of webbing abrasion sustained during the tests.

Figures 56 and 57 show the test results of Type I, 1-23/32-inch polyester webbing. This webbing exhibited a unique behavior; it creased and roped. This instability was due to the small thickness.

Figure 53A shows the pressure distribution data for Type IV, 3-inch polyester webbing. This webbing did not behave like the 1-3/4-inch pattern. The 3-inch polyester webbing creased, as Figure 51 shows, making its behavior very similar to the 3-inch nylon webbing. Figure 53A also shows how much the



ALBW: Actual Lap Belt Width.

Figure 53. Polyester Webbings (Readings Taken on Pelvic Bone).

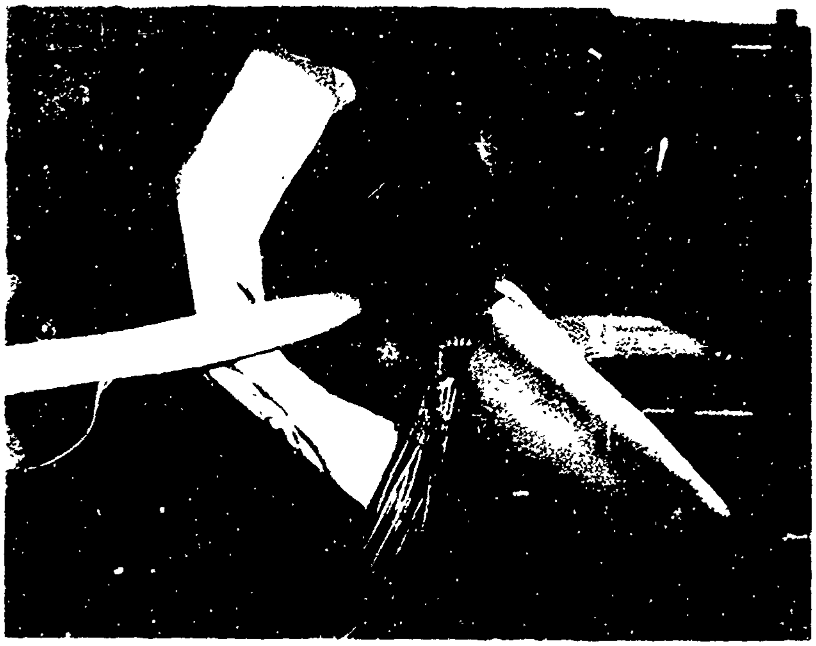


Figure 54. Type V, 1-3/4-Inch Polyester Webbing at 1500 Pounds Pulling Load.

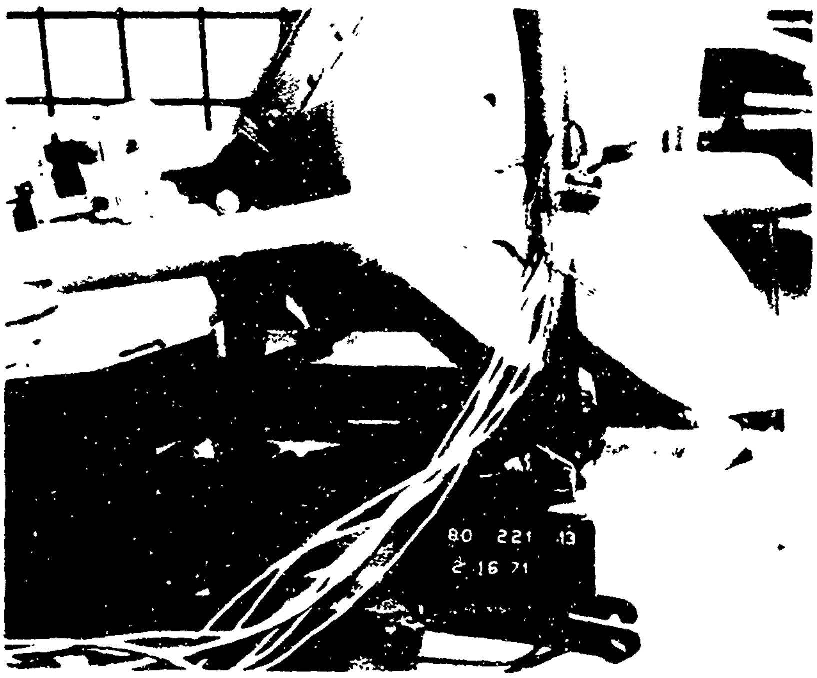


Figure 55. Type III, 1-23/32-Inch Polyester Webbing at 1500 Pounds Pulling Load.

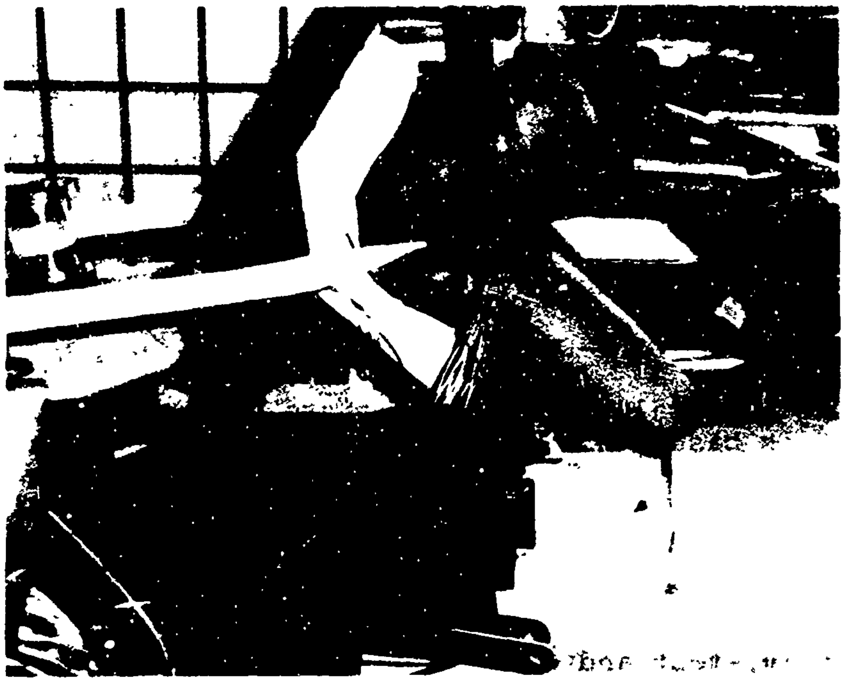


Figure 56. Type I, 1-23/32-Inch Polyester Webbing at 1000 Pounds Pulling Load.

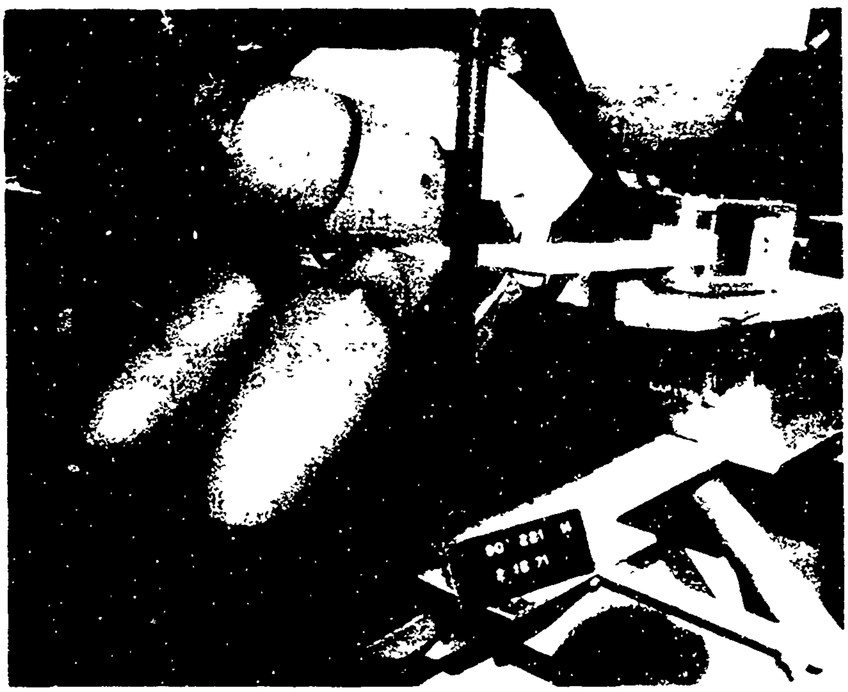


Figure 57. Type I, 1-23/32-Inch Polyester Webbing at 1000 Pounds Pulling Load.

creasing reduced the effective width of the webbing. The load cells located near the edges of the webbing did not show any load because the webbing creased and the edges pulled away from these load cells. Data showed that under a pulling load of 4100 pounds the creasing increased even more, to the point that the second load cell from the abdomen end of the webbing slipped out from under the webbing. This further reaffirmed the prior conclusion that a 3-inch-wide lap belt does not offer any real advantage.

WEBBING MATERIAL TRADE-OFF

The webbing material trade-off consists of two parts. The first part is based on information derived through extensive testing and evaluation conducted on various fabric materials. Table XXVII lists these fabric materials along with significant performance characteristics and other pertinent data.[89] The second part is based on information contained in Reference 94.

Unfortunately, test and evaluation data for webbings constructed from the many different fiber materials under development are very limited; therefore, the material trade-off conducted relied heavily on the data in Table XXVII. It was assumed in this trade-off that fiber performance characteristics were the same whether the fiber was used to construct fabric or webbings. An explanation of how the data in Table XXVII were transformed into the percentage readings shown in Table XXVIII follows.

It is evident from Table XXVII that the data are incomplete for some materials; e.g., for Beta 4190B there is no odor, carbon monoxide, or total organics data. Attempts to complete the data (including contact with the author of Reference 89) were not successful. Therefore, it was decided to use the materials for which the maximum amount of data were given in Table XXVII. This selection did not significantly restrict the choice of materials since the major groups were still present. The group included nylon, Teflon, Nomex, PBI, and X-400 (Durette).

Only the glass fiber group (Beta 4190B and Beta 4484/Teflon) and the metallic fiber group (nickel chromium) were eliminated. However, previous communications with the Fibrous Materials Branch, Nonmetallic Materials Division at WPAFB indicated that glass fiber webbings have very poor energy-absorption characteristics as well as poor abrasion resistance, while metallic fiber webbings are considered impractical (by the Air Force) due to the high cost and weight penalty.

TABLE XXVII. FABRIC CHARACTERISTICS SUMMARY

Fabric	Combustion Rates (in./sec)						Physical Characteristics												Outgassing			Cost	Availability	Supplier
	Physical Test Methods																							
	12						1		2	3	4	6	7	8	9	10	11	5	13					
	Weight (oz/sq yd)	Air	10 PSIA 35% O_2 65% N_2	6.2 PSIA, O_2	16.5 PSIA O_2	16.5 PSIA 60% O_2 40% N_2	Elongation (%)	Breaking Strength (Warp) (lbs/in.)	Tear Strength (Grams)	Wear Resistance (No. Cycles)	Folding Endurance (No Cycles)	Stiffness (in-lbs)	Abrasion (No. of Cycles)	Abrasion (No. of Cycles)	Air Permeability ($ft^3/ft^2/min$)	Electrostatic Charge (Nanocoulombs)	Thermal Conductivity (cal/sec/cm^2/(°C/cm))	Thickness (in.)	Odor (2.5 or lower is acceptable)	Carbon Monoxide (ugm/gm)	Total Organics (ugm/gm)			
Nylon	6.9			78			22	350	>6400	174	All Greater Than 5000	.002	2468	870	7.98	8.0	1.49×10^{-4}	.0145	12	1.2	.0003	$3/yd	Commercial	Stern & Stern
Beta 4190B	6.5	0	0	0.0	0	0	8.1	106	2400	148		.003	198	85	0.5	2.0	1.2×10^{-4}	.008 .009				$10/yd	Commercial	Owens/Corning
Beta 4484/Teflon	6.1	0	0	0.0	0	0	8.9	142	>6400	151		.003	125	1200	22.7	18.0	1.69×10^{-4}	.008				$6/yd	Available-Special Order	Owens/Corning
Teflon - Bleached T162-42	8.7		29	0.13	.435		67	59	5100	93		.0002	584	600	1.8	20.0	2.1×10^{-4}	.009	.9	0.7	34.0	$30/yd	Commercial	
Teflon - Natural	16.9			0.22	.725		56	172	5400	343		.002	1075	1952	11.2	32.0	1.8×10^{-4}	.018	1.7	4.2	9.0	$30/yd	Commercial	E. I. DuPont
Nomex (H.T. 90-40)	6.2		121	0.63	1.00		40	325	>6400	589		.001	943	260	4.9	8.0	1.58×10^{-4}	.013	7	0.4	1.0	$8/yd	Commercial	Stern & Stern
Nomex - Treated-$POCl_3$ NH_2	7.3			0.42			10	128	3000	353		.004	450	227	10.9	.06	1.6×10^{-4}	.014				$6/yd Treated	Experimental	Dynatech
PBI - Untreated	5.0			0.001	.009		20	149	>4600	206		.004	629	143	98.5	40.0	3.0×10^{-5}	.0135	5	2.4	3.0	$200/lb	Government Use Only	Celanese
PBI - Treated-$POCl_3$	8.0	0		0.0			60	188	6400	234		.002	2481	1651	26.9	2.6	1.2×10^{-5}	.017				$6/yd Treated	Experimental	Dynatech
PBI - Treated-$POCl_3$, NH_2	5.9			0.14			20	184	5700	721		.002	1200	1500	38.7	2.4	4.8×10^{-5}	.014					Experimental	Monsanto
X-400	6.2		S.E.*	0.31	.813		30	138	5900	126		.0003	467	116	89.1	2.0	1.3×10^{-4}	.012		3.7	0.0	$25-50/yd	Being Evaluated	Monsanto
X-410	5.0		S.E.*	0.29			14	200	3000	96		.001	145	65	28.9	18.0	1.8×10^{-4}	.0118	11	2.8	1.0		Experimental	Monsanto
X-420	5.0			0.30			13.3	124	4190	93		.002	100	350	43.4	.01	2.0×10^{-4}	.013					Experimental	Monsanto
Nickel Chromium (Karma Cloth or Chromel-R)	18.0	0	0	0.0	0	0		176	5400	269		.008	2034	977	68.8	0.0	N/A	.010				$150/lb $1500/yd	Available-Special Order	Fabric Research Laboratory
FYPRO 5007/7	6.0	0	0.29	0.7		0.8	24	154	3800	836		.003	217	41	49	12	2.0×10^{-4}	.015	0.7	4.0	1.0	$8.50/yd	Commercial	Trav's Mills
Kynol Fiber			27*	0.71*		5.0*	20	1.7**	-	-												$5.00/lb	Commercial	Carborundum Co.

Physical Test Methods:

1. FED STD 191, Method 5104
2. FED STD 191, Method 5132
3. FED STD 191, Method 5302
4. ASTM-D 2176
5. FED STD 191, Method 5030
6. FED 191, Method 5202
7. FED STD 191, Method 5306 (CS17 Wheel)
8. FED STD 191, Method 5304 (600 Grit Paper)
9. FED STD 191, Method 5450
10. Sweeney Test Method
11. Cenco-Fitch Test Method
12. FED STD 191, Method 5041
13. MSC-PA-D-67-13

*Self Extinguished

**Breaking tenacity, gm/denier

TABLE XXVIII. WEBBING MATERIAL TRADE-OFF RATINGS FOR THE AIRCREW RESTRAINT SYSTEM

Fabric	Stiff-ness Wt = 30	Combus-tion Rates Wt = 10	Weight Wt = 5	Wear Resis-tance Wt = 10	Abrasion Test Method 5306 Wt = 10	Abrasion Test Method 5304 Wt = 5	Electro-static Charge Wt = 5	Thermal Conduc-tivity Wt = 5	Cost Wt = 5	Odor Wt = 5	Carbon Monoxide Wt = 5	Total Organics Wt = 5	Total Wt = 10
Nylon	92.40 / 27.70	70.00 / 7.00	90.58 / 4.53	72.73 / 7.27	95.00 / 9.50	80.85 / 4.04	91.05 / 4.55	78.50 / 3.93	95.00 / 4.75	70.00 / 3.50	89.74 / 4.49	95.00 / 4.75	86.01
Teflon-Bleached T162-42	70.00 / 21.00	90.83 / 9.08	70.00 / 3.50	70.00 / 7.00	74.34 / 7.43	77.31 / 3.87	83.15 / 4.15	70.00 / 3.50	76.75 / 3.84	94.76 / 4.74	93.03 / 4.65	70.00 / 3.50	76.26
Teflon-Natural	71.64 / 21.50	88.27 / 8.83	71.20 / 3.56	78.52 / 7.85	80.00 / 8.00	95.00 / 4.75	75.25 / 3.76	74.20 / 3.71	76.75 / 3.84	92.79 / 4.64	70.00 / 3.50	88.38 / 4.19	78.13
Nomex (H.T. 90-40)	81.85 / 24.55	74.80 / 7.48	90.54 / 3.56	90.10 / 9.01	78.59 / 7.86	72.86 / 3.64	91.05 / 4.55	77.20 / 3.86	91.62 / 4.58	81.00 / 4.05	95.00 / 4.75	94.26 / 4.71	82.60
PBI-Untreated	80.20 / 24.06	95.00 / 9.50	95.00 / 4.75	73.80 / 7.38	75.20 / 7.52	71.33 / 3.56	70.00 / 3.50	95.00 / 4.75	40.00 / 2.00	85.48 / 4.37	91.85 / 4.59	92.79 / 4.64	80.62
X-400 Durette	76.31 / 22.90	85.05 / 8.51	88.85 / 4.44	71.11 / 7.11	73.47 / 7.35	70.98 / 3.55	95.00 / 4.75	81.10 / 4.05	70.00 / 3.50	95.00 / 4.75	73.30 / 3.67	95.00 / 4.75	79.33
X-410	95.00 / 28.50	85.70 / 8.57	92.77 / 4.64	70.10 / 7.01	70.00 / 7.00	70.31 / 3.52	84.47 / 4.22	74.20 / 3.71	95.00 / 4.75	72.20 / 3.61	78.55 / 3.93	94.26 / 4.71	84.17
Fypro 5007/7	77.40 / 23.20	72.55 / 7.26	93.74 / 4.69	95.00 / 9.50	70.78 / 7.08	70.00 / 3.50	88.43 / 4.42	71.40 / 3.57	91.28 / 4.56	95.00 / 4.75	71.30 / 3.57	94.26 / 4.71	80.81

The fabrics were relatively rated to the parameters and weight factors as shown in Table XXVIII; the last column shows the total rating for each material.

An effort was made to use as many parameters as possible in order to make the evaluation as comprehensive as possible. The parameter designated Stiffness in Table XXVIII does not use the data of the column designated Stiffness in Table XXVII. For the purposes of this report the term stiffness was used to identify the load-elongation characteristics of a webbing material. Stiffer material will elongate less at a given load. The rating range was established to reflect the basic ground rule that no material is perfect, thereby receiving a 100 percent rating, and, if a material rates below 70, it should probably not be included in the trade-off. The stiffness parameter of Table XXVIII represents the force-deflection characteristics of the material using the data listed in Thickness, Breaking Strength, and Elongation columns. To make the force-deflection evaluation on a comparable base, all materials were considered to have the same thickness (0.018 inch). It was assumed that an increase in thickness would proportionally increase the breaking strength as well as the weight, and these variations were considered when the percentage rating for the stiffness and weight parameters of Table XXVIII were prepared.

It is possible that the constant thickness adjustment for all materials might offset the cost parameters also. However, the cost data were not adjusted because a proportional increase in cost due to an increase in thickness might not be a good assumption. A check determined that cost adjustment had no effect on the final rating of the materials. The best percentage rating assignable was 95 and the worst was 70 for the parameters in Table XXVIII. Intermediate ratings were interpolated. For example, consider the Abrasion column of Table XXVII. (Note 8 in the Abrasion column refers to FED STD 191, Method 5304.) The greater the number of cycles listed, the better the material abrasion resistance, which resulted in higher ratings being assigned in Table XXVIII. The Abrasion column in Table XXVII shows that the natural Teflon provides abrasion resistance for the greatest number of cycles (1952); therefore, it was given the best percentage rating (95). Fypro 5007/7 provides abrasion resistance for the smallest number of cycles (41); thus, it was given the lowest percentage rating (70). The percentage rating for the nylon was calculated as follows:

$$\frac{870 - 41}{1952 - 41} (25) + 70 = 80.85$$

Slide rule accuracy was used for all calculations.

For the cost parameter of Table XXVIII, $3 per yard for nylon was assigned the best rating while $40 per yard for Durette (X-400) was assigned the lowest rating. The cost for PBI was given as $200 per pound, so that rating per yard for this material was estimated. Cost data for Durette (X-410) and odor for Durette (X-400) were not given in Table XXVII. Since only one parameter was involved for each material, highest percentage ratings for these two parameters were assigned. It was felt that this would be fair and not jeopardize the trade-off.

The stiffness parameter of Table XXVIII was assigned the weighting factor shown as a result of the information obtained from the variables analysis conducted. The abrasion parameter determined through testing according to FED-STD 191, Method 5306, was assigned a higher weighting factor than the other abrasion parameter listed because, of the two fabric testing methods, Method 5306 more closely approximates the abrasion test used for webbings.

The parameter of combustion rate, having to do with the flammability of the material, was given a weighting factor equivalent to the highest abrasion category to signify its importance. The parameter of wear resistance was also given a weighting factor equivalent to the parameters of combustion rate and the highest abrasion resistance since webbings used for restraint systems should have high wear resistance. The rest of the parameters were assigned equal weighting factors since their importance was considered to be relatively low and about equivalent.

Nylon was rated first in the trade-off; however, the materials considered in this portion of the trade-off did not include polyester. A choice between nylon and polyester was then required. This was the purpose of the second part of the trade-off. Table XXIX, taken from an SAE paper,[94] indicates that polyester has some advantages over nylon. Of course, the great advantage of polyester is the higher force-deflection characteristics which were determined to be highly desirable during the variables analysis.

According to experts in the field, combustion rates for nylon and polyester in air are about the same.

Previous information received from a webbing manufacturer indicated that polyester webbings are somewhat more expensive. For example, considering a quantity of 2500 yards, the 3-inch-wide nylon webbing, Type IX per MIL-W-4088, will cost $40.40 per 100 yards, while the 3-inch-wide polyester webbing, Type IV per MIL-W-25361, will cost $46.20 per 100 yards. When

TABLE XXIX. FABRIC GENERAL PROPERTIES		
Property	Nylon	Polyester
Tensile Strength	High	High
Elongation	Medium	Low
Resistance to Aging	Good	Good
Moisture	Very Good	Excellent
Heat Degradation	Very Good	Excellent
Mildew	Good	Good
Flammability	Fair	Fair

asked about service life for nylon and polyester webbings, the author of Reference 91 replied, "With regard to service life, neither polyester or nylon are adveresely affected by cold or rain since they are not subject to mildew. Both are, however, affected by exposure to sunlight. Under glass, polyester is practically unaffected by ultraviolet but nylon still loses tensile strength on prolonged exposure, whether under glass or not. Additionally, heat can be a factor, particularly on nylon, when long exposures to temperatures in excess of 150°F are encountered."

On the subject of abrasion resistance webbing, Types II and IV, MIL-W-25361 (polyester webbing specification) was very poor.[91] These materials should definitely be latex-treated to increase their service life.[91] In both cases, abrasion resistance could be increased by the use of large filament yarns which are available in both polyester and nylon.

The poorer abrasion characteristics of the polyester webbings (Types III, IV, and V per MIL-25361) as compared to nylon (Types IX, XXV, and XXVIII per MIL-W-4088) caused by the different weave pattern were confirmed during the static tests conducted to investigate the effect on pressure applied to the occupant as a function of lap-belt width. For these reasons, a weave pattern similar to Type XXVII per MIL-W-4088 would be desirable for all the webbings used in the optimum aircrew restraint system.

Consideration of all this information, in addition to the major advantage of reduced elongation, led to the decision to use polyester webbing material for the restraint system.

OVERALL RESTRAINT SYSTEM CONCEPT TRADE-OFF

Nine concepts were selected for the trade-off (see Figures 58 through 66). All nine concepts can be classified under three main groups depending on the design arrangement of the shoulder harness.

In the first group (Concepts 1, 2, and 3), the webbing attached to the inertia reel extends and connects directly to the single release buckle. It requires two single inertia reels (or a double-strap inertia reel) and eliminates the need for shoulder harness adjusters. The principal advantages of this group when compared to the other two groups are simplicity and comfort. Some commercial airlines use this concept in their pilot and copilot restraint systems. Comparatively poor lateral restraint of the upper torso is the main disadvantage.

The shoulder harness design of the second group (Concepts 4, 5, and 6) incorporates the Y- or V-type of shoulder harness used by crewmen of military aircraft and requires a single inertia reel and shoulder harness adjusters. This group is characterized by lower weight, better reliability, and better maintainability than the other two groups, as well as comfort, good service life, and low cost. Poor longitudinal and lateral restraint of the upper torso are the main disadvantages. The poor longitudinal restraint results from the single inertia reel used because, for identical crash conditions, the deceleration load on the single strap will be twice as high as for the double-strap inertia reel or two single-strap reels. This will result in a greater upper torso deflection since, for the same webbing material, higher loads mean higher elongation.

In the third group (Concepts 7, 8, and 9), the reflected shoulder strap approach is used. This type of shoulder harness design is used at the present time by the U. S. Air Force in the F-111 aircraft and by the Royal Air Force in England. It has two single inertia reels (or a double-strap inertia reel) as well as shoulder harness adjusters. The webbing from the inertia reel passes through a roller attached on the horse collar and is permanently fastened at the top of the seat back on the other side (webbing from the inertia reel located toward the left side of the seat is fastened on the right side). This arrangement creates a loop for each inertia reel webbing, further reducing the deceleration loads transmitted to the reels during a crash. Hence, the upper torso deflections will be even smaller; therefore, this group provides better longitudinal restraint than either of the other designs. Comparative increases in weight, cost, and complexity are the main disadvantages.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Single Tie-Down Strap

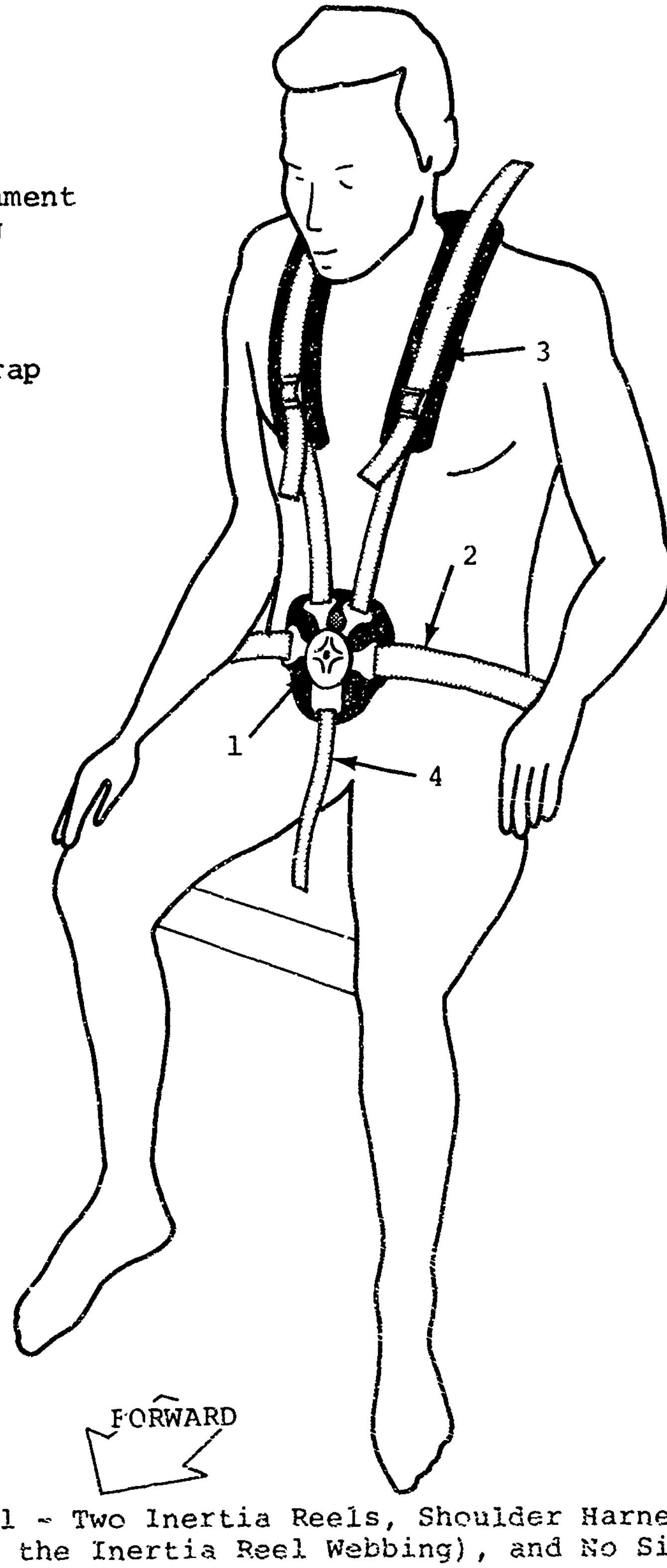


Figure 58. Concept 1 - Two Inertia Reels, Shoulder Harness (Part of the Inertia Reel Webbing), and No Side Straps.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Single Tie-Down Strap
5. Side Strap

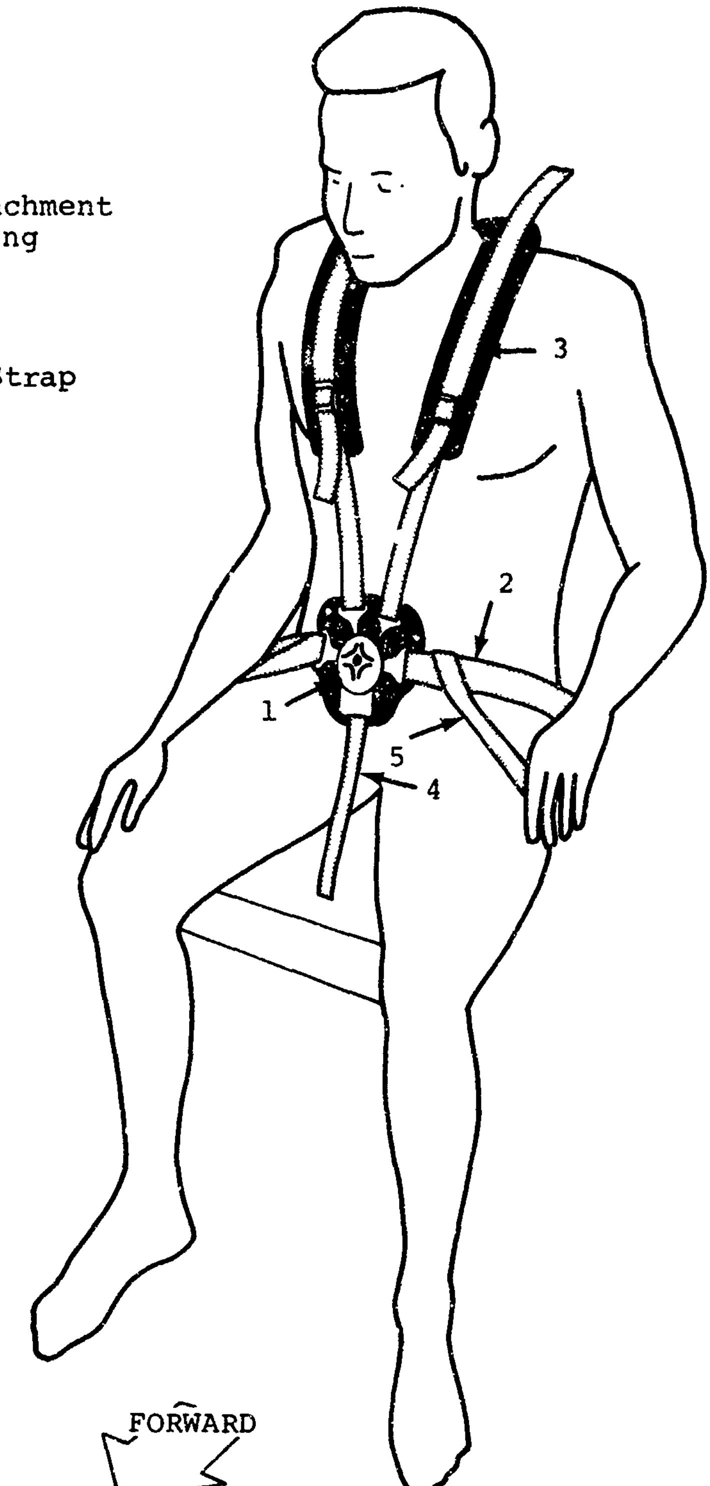


Figure 59. Concept 2 - Two Inertia Reels, Shoulder Harness (Part of the Inertia Reel Webbing), and Side Straps.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Double Tie-Down Strap
5. Side Strap

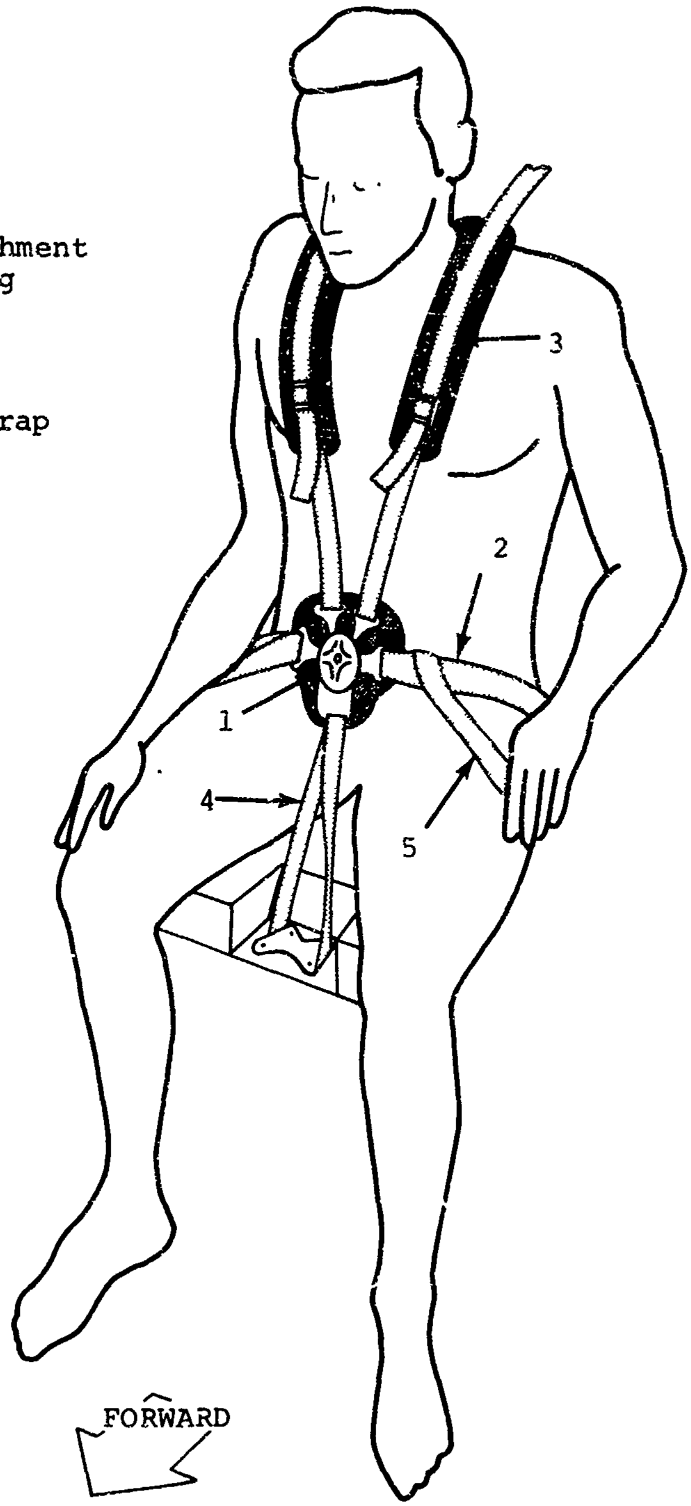


Figure 60. Concept 3 - Two Inertia Reels, Shoulder Harness (Part of the Inertia Reel Webbing), Side Strap and Double Tie-Down Strap.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Single Tie-Down Strap

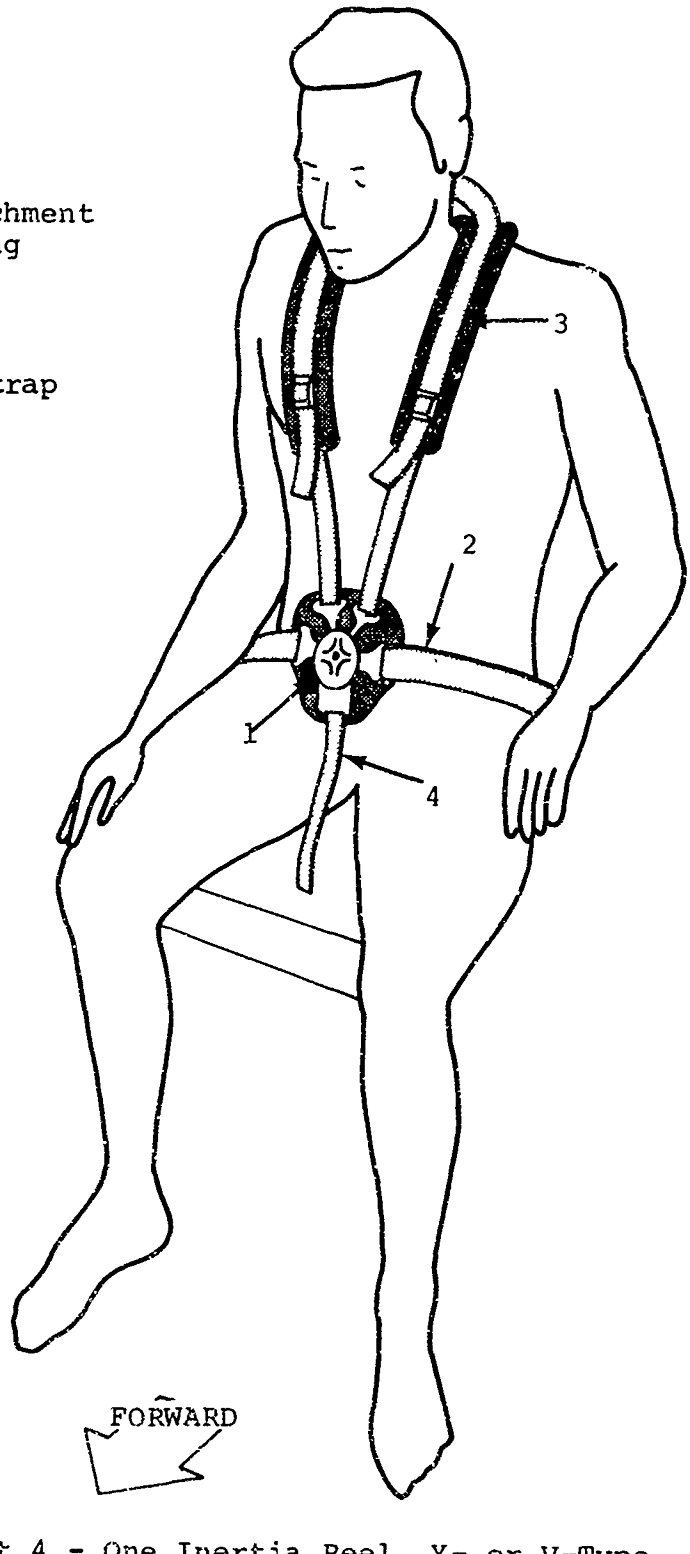


Figure 61. Concept 4 - One Inertia Reel, Y- or V-Type Shoulder Harness, and No Side Straps.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Single Tie-Down Strap
5. Side Strap

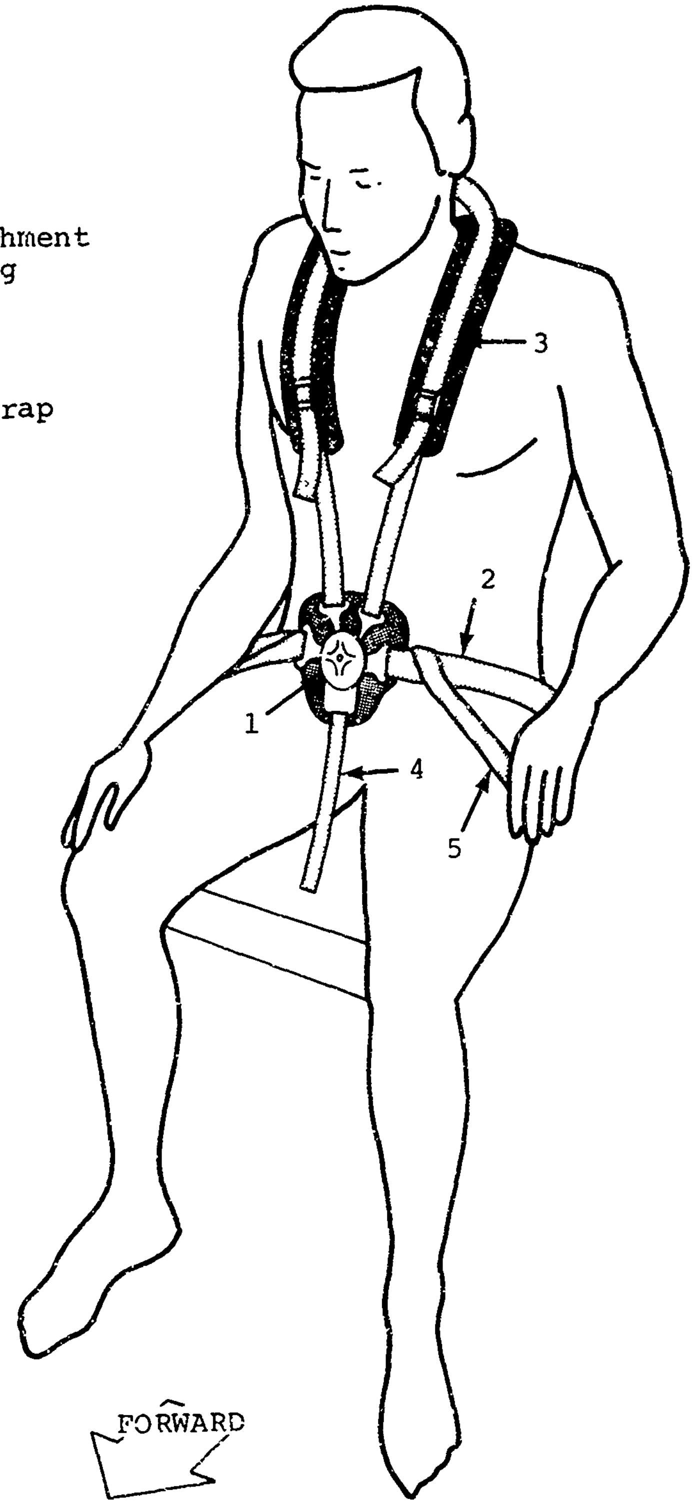


Figure 62. Concept 5 - One Inertia Reel, Y- or V-Type Shoulder Harness, and Side Straps.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Double Tie-Down Strap
5. Side Strap

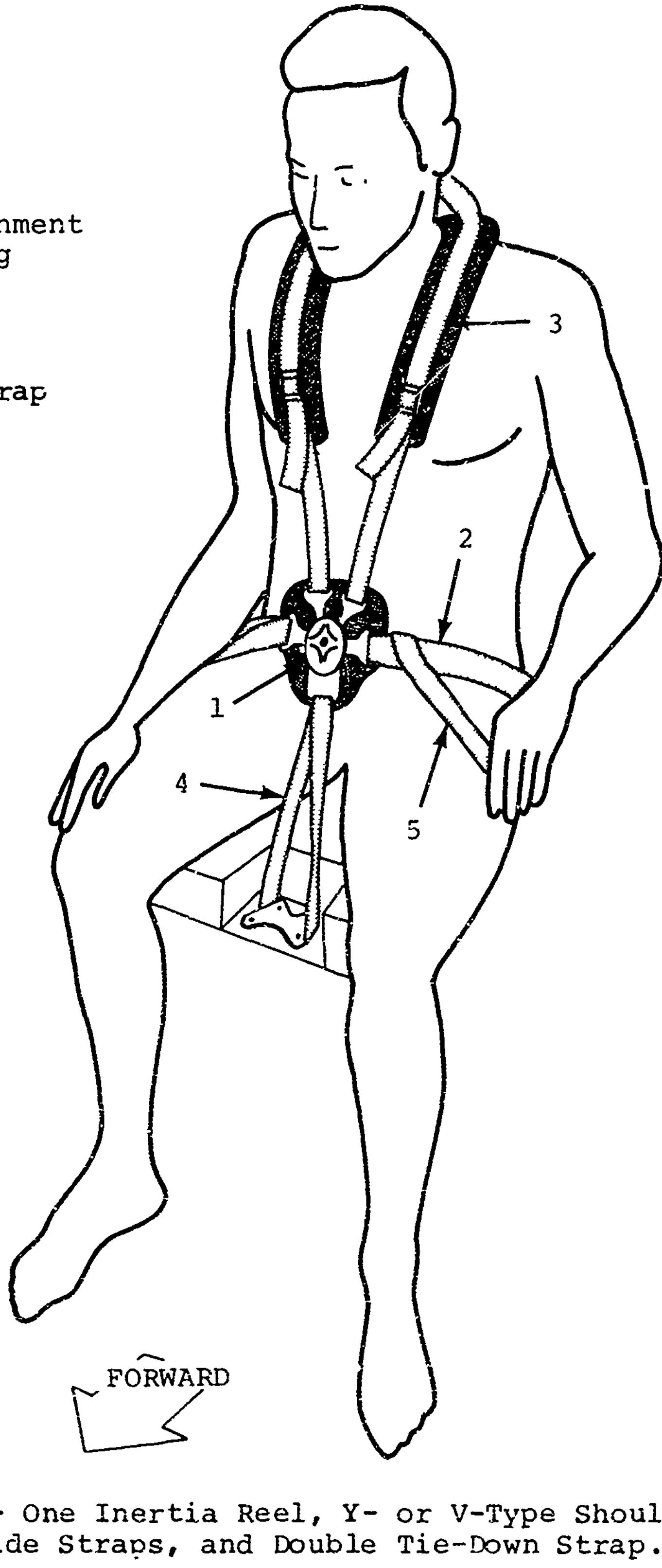


Figure 63. Concept 6 - One Inertia Reel, Y- or V-Type Shoulder Harness, Side Straps, and Double Tie-Down Strap.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Single Tie-Down Strap
5. Reflected Shoulder Strap

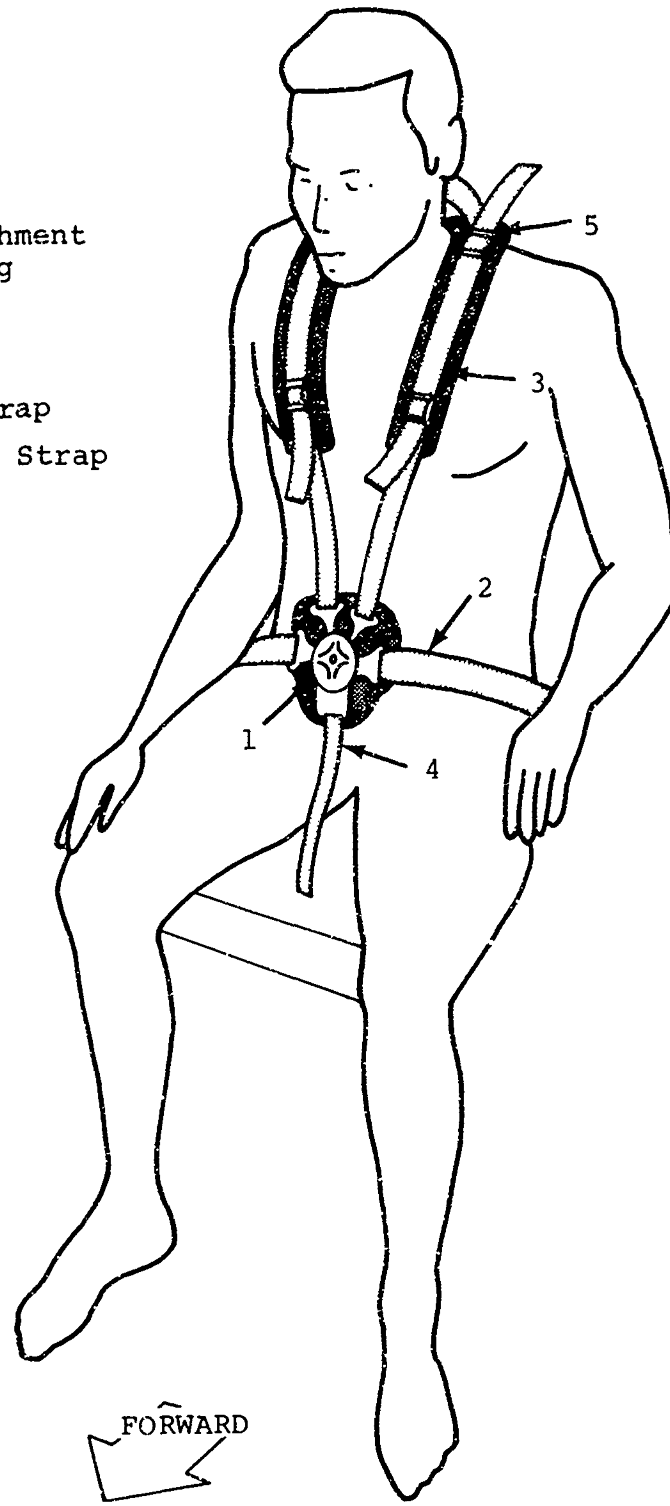


Figure 64. Concept 7 - Two Inertia Reels, Reflected Shoulder Harness, and No Side Strap.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Single Tie-Down Strap
5. Side Strap
6. Reflected Shoulder Strap

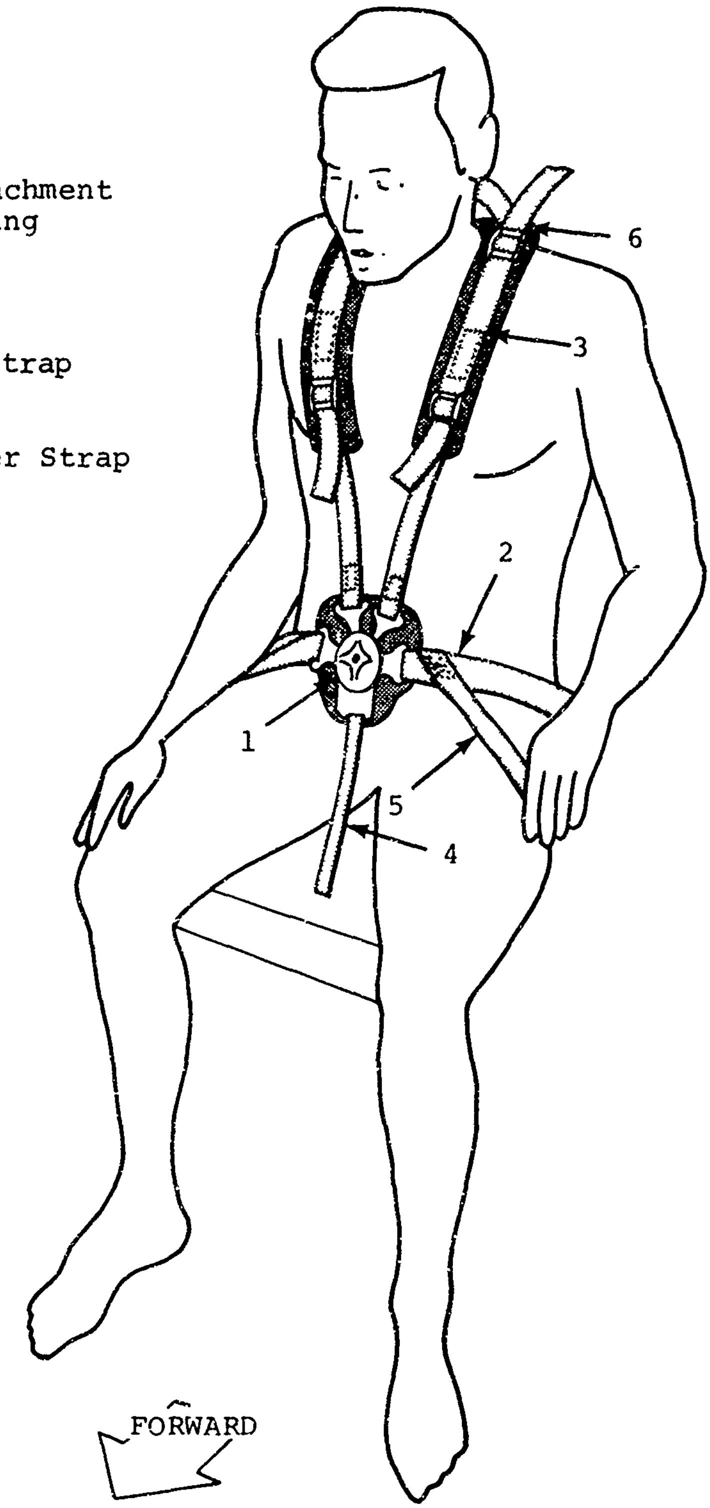


Figure 65. Concept 8 - Two Inertia Reels, Reflected Shoulder Harness, and Side Straps.

ITEM IDENTITY

1. Single-Point Attachment and Release Fitting
2. Lap Belt
3. Shoulder Strap
4. Double Tie-Down Strap
5. Side Straps
6. Reflected Shoulder Strap

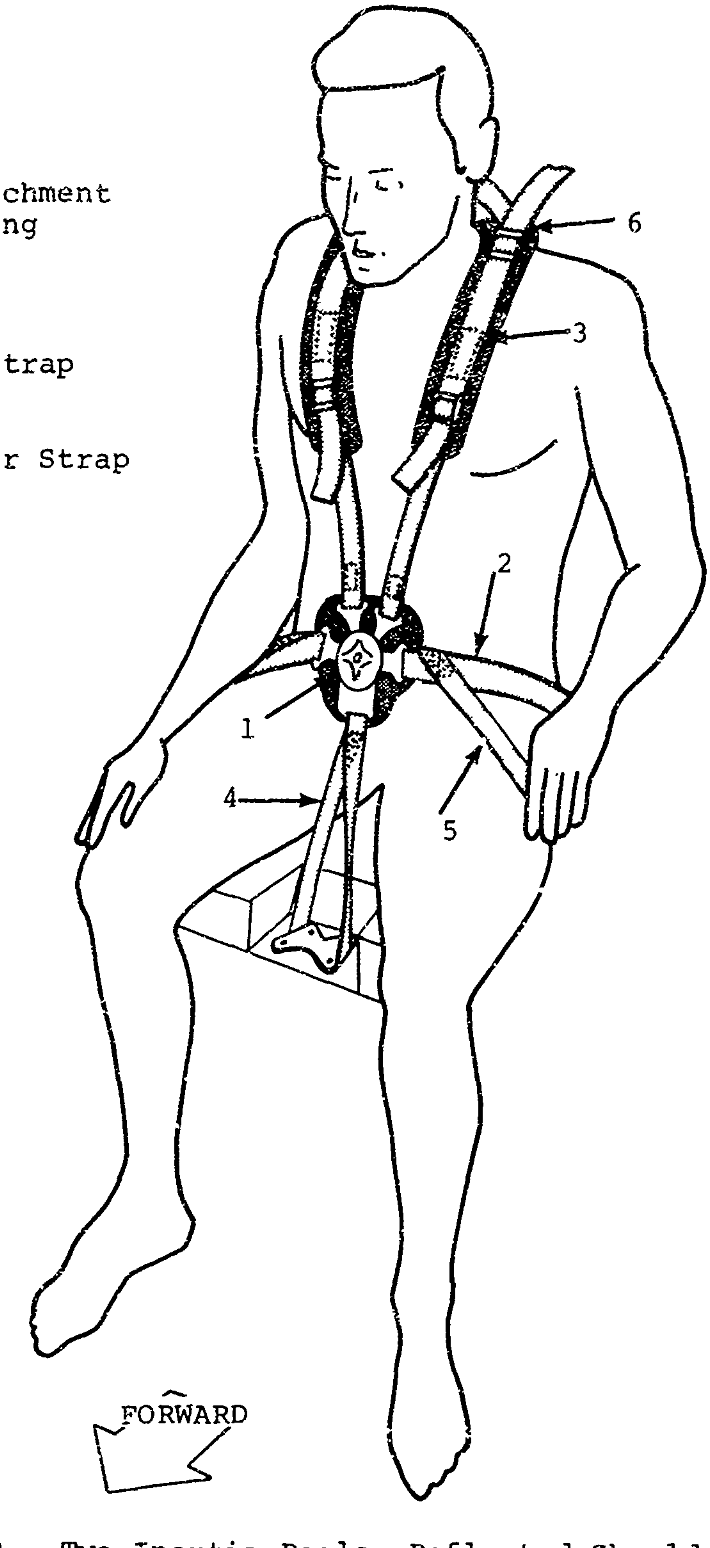


Figure 66. Concept 9 - Two Inertia Reels, Reflected Shoulder Harness, Side Straps, and Double Tie-Down Strap.

Variations of the lap-belt design for each of the three shoulder-harness design types discussed constitute the nine concepts analyzed in this trade-off.

The lap belt with a single tie-down strap (Concepts 1, 4, and 7) maintains simplicity. The addition of side straps (Concepts 2, 5, and 8) makes the system somewhat more complex but considerably increases the lateral restraint. The replacement of the single lap-belt tie-down strap with a double strap (Concepts 3, 6, and 9) further increases lateral restraint. The unfounded fear that the single lap-belt tie-down strap might produce injury during a crash has prevented its wide use. The use of a double strap largely dispels this fear.

Two trade-offs were performed using the nine design concepts. During the first trade-off (Table XXX), each concept was rated as a system relative to a particular parameter. For example, the number of adjusters used by each system and their effect on the relative rating of the various parameters were not considered during the first trade-off. These effects were considered during the second trade-off (Table XXXI).

The two trade-offs were conducted to examine the possibility that, while a concept might get a high total rating when considered as a system, it might get a lower total rating when the effect of individual parts was considered. The results presented in Tables XXX and XXXI show that this was indeed true for the majority of the concepts under consideration.

It was assumed during both trade-offs that each conceptual design used the same type of webbing and hardware attachments. The buckle and the adjusters were chosen from among those available on the market today.

The concepts were rated relative to the parameters and weight factors shown in Table XXXII during both trade-offs.

Under some of the parameters, additional items were considered. Under cost, for instance, the simplicity of the system was considered. Under ease of ingress, the confusion that a design might create to the user and the effect of the number of connections and adjustments were considered.

In general, a simplified system (Concept 1) will be rated high in cost, service life, reliability (fewer components to malfunction), maintainability (fewer components to maintain), and weight, and will be rated relatively low in the area of restraint. Adding components such as side straps, double lap-belt tie-down strap, and reflected shoulder harness will lower the ratings for cost, service life, reliability, maintainability, and weight, but will increase the ratings for restraint.

TABLE XXX. RESULTS OF FIRST TRADE-OFF IN WHICH COMPONENT DETAILS WERE NOT CONSIDERED													
Concept	Lateral Restraint Wt = 15	Longitudinal Restraint Wt = 15	Comfort Wt = 15	Ease of Egress Wt = 15	Movement Restriction Wt = 10	Ease of Ingress Wt = 10	Cost (Simplicity) Wt = 5	Service Life Wt = 5	Reliability Wt = 5	Maintainability Wt = 3	Weight Wt = 2	Total	Rating
1	65 / 9.75	85 / 12.75	90 / 13.50	95 / 14.25	90 / 9.00	95 / 9.50	92 / 4.60	90 / 4.50	90 / 4.50	90 / 2.70	90 / 1.80	86.85	9
2	80 / 12.00	92 / 13.80	80 / 12.45	95 / 14.25	87 / 8.70	95 / 9.50	88 / 4.40	87 / 4.35	87 / 4.35	87 / 2.61	87 / 1.74	88.15	7
3	82 / 12.30	93 / 13.95	85 / 12.75	95 / 14.25	87 / 8.70	95 / 9.50	85 / 4.25	85 / 4.25	85 / 4.25	85 / 2.55	85 / 1.70	88.45	5
4	70 / 10.50	80 / 12.00	93 / 13.95	95 / 14.25	92 / 9.20	95 / 9.50	95 / 4.75	92 / 4.60	93 / 4.65	93 / 2.79	93 / 1.86	88.05	8
5	85 / 12.75	87 / 13.05	86 / 12.90	95 / 14.25	89 / 8.90	95 / 9.50	91 / 4.55	89 / 4.45	90 / 4.50	90 / 2.70	90 / 1.80	89.35	4
6	87 / 13.05	88 / 13.20	88 / 13.20	95 / 14.25	89 / 8.90	95 / 9.50	88 / 4.40	87 / 4.35	88 / 4.40	88 / 2.64	88 / 1.76	89.65	2
7	80 / 12.00	88 / 13.20	87 / 13.05	95 / 14.25	88 / 8.80	95 / 9.50	88 / 4.40	88 / 4.40	87 / 4.35	87 / 2.61	87 / 1.74	88.30	6
8	95 / 14.25	95 / 14.25	80 / 12.00	95 / 14.25	85 / 8.50	95 / 9.50	84 / 4.20	85 / 4.25	84 / 4.20	84 / 2.52	84 / 1.68	89.60	3
9	97 / 14.55	96 / 14.40	82 / 12.30	95 / 14.25	85 / 8.50	95 / 9.50	81 / 4.05	83 / 4.15	82 / 4.10	82 / 2.46	82 / 1.64	89.90	1

TABLE XXXI. RESULTS OF SECOND TRADE-OFF IN WHICH COMPONENT DETAILS WERE CONSIDERED													
Concept	Lateral Restraint Wt = 15	Longitudinal Restraint Wt = 15	Comfort Wt = 15	Ease of Egress Wt = 15	Movement Restriction Wt = 10	Ease of Ingress Wt = 10	Cost (Simplicity) Wt = 5	Service Life Wt = 5	Reliability Wt = 5	Maintainability Wt = 3	Weight Wt = 2	Total	Rating
1	65 / 9.75	85 / 12.75	90 / 13.50	95 / 14.25	90 / 9.00	95 / 9.50	92 / 4.60	90 / 4.50	90 / 4.50	90 / 2.70	90 / 1.80	86.85	5
2	80 / 12.00	92 / 13.80	80 / 12.00	95 / 14.25	87 / 8.70	90 / 9.00	85 / 4.25	85 / 4.25	85 / 4.25	85 / 2.55	85 / 1.70	86.75	7
3	82 / 12.30	93 / 13.95	82 / 12.30	95 / 14.25	87 / 8.70	90 / 9.00	83 / 4.15	83 / 4.15	83 / 4.15	83 / 2.49	83 / 1.66	86.80	6
4	70 / 10.50	80 / 12.00	90 / 13.50	95 / 14.25	92 / 9.20	90 / 9.00	94 / 4.70	90 / 4.50	91 / 4.55	91 / 2.73	91 / 1.82	86.75	7
5	85 / 12.75	87 / 13.05	80 / 12.00	95 / 14.25	89 / 8.90	85 / 8.50	87 / 4.35	85 / 4.25	86 / 4.30	86 / 2.58	86 / [illegible]	86.65	8
6	87 / 13.05	88 / 13.20	82 / 12.30	95 / 14.25	89 / 8.90	85 / 8.50	85 / 4.25	83 / 4.15	84 / 4.20	84 / 2.52	84 / 1.68	87.00	4
7	80 / 12.00	88 / 13.20	85 / 12.75	95 / 14.25	88 / 8.80	90 / 9.00	88 / 4.40	87 / 4.35	88 / 4.40	88 / 2.64	88 / 1.76	87.55	2
8	95 / 14.25	95 / 14.25	75 / 11.25	95 / 14.25	85 / 8.50	85 / 8.50	81 / 4.05	82 / 4.10	83 / 4.15	83 / 2.49	83 / 1.66	87.45	3
9	97 / 14.55	96 / 14.40	77 / 11.55	95 / 14.25	85 / 8.50	85 / 8.50	79 / 3.95	80 / 4.00	81 / 4.05	81 / 2.43	81 / 1.62	87.80	1

TABLE XXXII. PARAMETERS AND WEIGHT FACTORS FOR CONCEPT TRADE-OFFS	
Parameter	Weight Factor
Lateral Restraint	15
Longitudinal Restraint	15
Comfort	15
Ease of Egress	15
Ease of Ingress	10
Movement Restriction	10
Cost	5
Service Life	5
Reliability	5
Maintainability	3
Weight	2

Concept 9 received the highest total rating during both trade-offs and was therefore selected as the design to be fabricated and tested.

EVALUATION OF POWER RETRACTION AND STANDARD MIL-R-8236C INERTIA REELS

Two types of inertia reels are available on the market today: the standard inertia-locking, shoulder-harness take-up reel and the power-retracting, inertia-locking, shoulder-harness take-up reel. Both inertia reels meet the requirements of MIL-R-8236, Type MA-6.

During operation, the standard inertia reel is free to unreel against a small spring load whioh takes up the slack that might exist in the shoulder straps. The reel will lock and restrain the torso at a strap acceleration of 2 to 3G. The power-retracting inertia reel operates the same as the standard inertia reel except that, when the power-retraction device is activated, the occupant is pulled back into the seat with the reel locked.

The following paragraphs discuss the operational characteristics of the power-retracting inertia reel and present the advantages and/or disadvantages of these characteristics relative to the standard inertia reel.

Means of Activating the Power Retraction Device

Power-retracting inertia reels available on the market today consist of three components: the reel, the power-retraction device, and the gas generator. When the reel is actuated manually, an electrical switch within easy reach of the crew-member activates a valve which releases the gas that produces the power to retract the shoulder harness into the reel.

There are small variations in the operational data between power-retracting inertia reels produced by different manufacturers (especially longer retraction times), but for this analysis, the following operational data were used.

Power retraction is completed 0.3 sec after initiation. The reel-in velocity with the occupant is somewhat less than 9 ft/sec and the haul-back strap length is 18 inches.

Manual actuation of powered inertia reels is satisfactory for ejection seat application in aircraft; however, to be effective in the crash environment, a sensor switch that will detect the occurrence of a crash and automatically actuate the system must be added. The Government's recent requirement that passive inflatable occupant restraint systems (PIORS) be developed for use in automobiles has resulted in intensive crash sensor development work.[95]

Two basic approaches to crash detection are currently under consideration. One may be classified as predictive or anticipatory and the other as active or post-impact. The predictive sensor approach makes the crash/noncrash determination prior to impact, while the active makes the determination during impact.

The information which must be derived for crash protection is common to all predictive systems, although the basic sensor may vary. The basic information which must be determined relative to the collision object under all weather and environmental conditions consists of:

- Relative velocity
- Distance to obstacle
- Strength of obstacle (degree of hazard)
- Height of obstacle

The types of predictive sensors which have been considered are:

- Radar
- Laser
- Passive infrared
- Acoustic

An evaluation of the present state of the art of four predictive sensor schemes indicates that the major problems are:

- Radar
  - Limited ability to assess degree of hazard
  - Limited ability to define zone of interest
- Laser
  - Inability to assess degree of hazard
  - Not an all-weather system
- Passive Infrared
  - Inability to assess degree of hazard
  - Not an all-weather system
- Acoustic
  - Inability to assess degree of hazard
  - Background acoustic interference around traffic

There are additional problems in integrating the sensor into the aircraft, servicing the devices, system reliability, and relative cost. These problems are more severe than those experienced with an active or postcrash sensor. Considerably more development work must be performed before reliable production models of predictive sensors become available.

The basic requirement for an active or postcrash detector is to provide reliable and economical crash/noncrash discrimination for predetermined levels of impact in a given angular zone of interest. The three crash characteristics being analyzed by the crash sensor are amplitude, duration, and direction of impact.

Many approaches can be used in the design of an active sensor:

- Acceleration
  - Seismic mass
  - Piezoelectric
- Force
  - Distortion
  - Measurement

After a variety of sensors were developed, it was determined that a spring-mass accelerometer best satisfied the basic sensor requirements. A spring-mass double integrating accelerometer has been built in uni-, bi-, and omnidirectional configurations; however, this mechanical sensor has several disadvantages:

- Sensitivity limited by friction levels
- Slow actuation speed
- Effective threshold varied as function of angle of impact
- Malfunction diagnosis difficulty
- Making inoperative for maintenance
- Redundant sensor combinations difficult
- Automatic relock difficult
- Mounting location limitations

Some of these problems were solved by one manufacturer by representing the spring in the spring-mass systems by a permanent magnet and the mass by a steel ball. Under normal operation the ball rests in an indent above the magnet. Under full impact conditions the ball moves across an essentially frictionless surface and connects the contact ring to the base conductor to complete the circuits for initiation of gas release from the gas generator.

Reliability predictions for active sensors are based upon extrapolation of test results of a single crash sensor. An acceptable probability of satisfactory system operation cannot be established in this manner. Multi-detector sensors must be included to obtain adequate reliability. Redundant sensor

mechanization can substantially reduce probabilities of inadvertent firing without significantly degrading command firing performance.

For our analysis, the operating time of the active or post-impact crash sensor is important. The models available on the market today require approximately 20 msec from crash initiation for the gas generator to actuate.

Aircraft crash data indicate that it takes approximately 60 msec from the initiation of the crash for the maximum crash loads to be transmitted to the seat occupant. This means that the seat occupant should be optimally restrained within 60 msec of initial impact. However, since 20 msec are required for the sensor to function, only 40 msec remain for a power inertia reel to position the occupant.

Based on the operational characteristics of the power-retracting inertia reels available, there is a possibility that there will be no webbing retraction within 60 msec. As stated earlier, power retraction is completed 0.3 sec after initiation. At a reel-in velocity of 9 ft/sec it will take about 0.166 sec to retract 18 inches (1.5 feet) of webbing. This indicates a delay of over 0.1 sec from actuation to haul-back. This time delay is needed in order to develop sufficient pressure to perform work.[96] In such a case, it is obvious that retraction will not take place before the maximum crash loads are transmitted to the seat occupant.

The use of a power-retracting inertia reel presents no advantages over the standard inertia reel during the major impact, since there is not enough time to reel in any webbing before the maximum crash loads are transmitted to the occupant.

Two approaches can be considered at this point: (1) reduce the time from actuation to initiation as much as possible or (2) increase the reel-in velocity.

Considering the first approach, assume that the time delay from actuation to initiation of haul-back is reduced to 5 msec and that the power reel system uses an active sensor. There are now 35 msec available to haul back the occupant. At 9 ft/sec reel-in velocity, 0.315 foot or about 3.78 inches of webbing will be retracted in 0.035 sec. Whether this amount of retraction will be sufficient to haul the occupant back into the seat will depend on the occupant position at the initiation of the crash. However, it is obvious that 35 msec is not sufficient time to reel in 18 inches of webbing if such a requirement exists.

Considering the second approach (increasing the reel-in velocity), assume that the available time to reel in 18 inches of webbing is 35 msec. This would require a reel-in velocity of approximately 63 ft/sec or about 43 mph which fa. exceeds a safe haul-back velocity for the seat occupant. Research with PIORS has shown that 10 to 15 mph is a safe rebound velocity range from the standpoint of injuries to the occupant, indicating that 9 ft/sec (approximately 13 mph) reel-in velocity is just about the maximum.

It appears that the active or post-impact crash sensor is not the right type of crash detector to use in conjunction with a power-retracting inertia reel. The predictive or anticipatory type of crash detector will have to be used for an effective performance of the power-retracting inertia reel.

In addition to the problems confronting this type of crash detector, detection time will be very important. Traffic dynamics studies for cars using predictive sensors have indicated that unacceptably high inadvertent firing rates can be anticipated if the distance to the object at point of air cushion firing exceeds an equivalent 125 msec. If about 125 msec turns out to be a maximum limit for aircraft, the time delay from actuation to actual retraction of the power inertia reel will be a very important parameter, and will have to be reduced to a minimum. This factor, in turn, might make it necessary to have the gas generator close to the power-retraction device.

At this time, additional possible problem areas are difficult to assess because the operational characteristics of the predictive sensor have not been developed.

In conclusion, using a post-impact crash sensor to actuate the power-retracting inertia reel does not provide advantages over the standard inertia reel in restraining the seat occupant during the major impact. This situation might be improved if working models of predictive sensors become available.

Merit of the Device as a Means of Automatically Removing Incapacitated or Unconscious Crewmembers From Aircraft Controls

At the present time power-retracting inertia reels are used with restraint systems of ejection seats and fixed seats of ejecting cockpits (F-111 aircraft). The primary reason in both cases is that, in order to avoid spinal injuries, the occupant must be properly positioned before seat or cockpit ejection takes place. When the seat-ejection sequence is properly timed, the power-retracting inertia reel is actuated

first and the seat occupant is pulled back into the seat with the reel locked before seat ejection takes place, thus minimizing the possibility of spinal injuries.

One reason given for the use of automatic sequencing of the power reel on ejection seats (Air Force)[97] is to protect the out-of-position pilot or copilot from the effects of an accidental seat-ejection initiated by mistake by his partner.

The possibility of a pilot becoming incapacitated during the critical moments of a flight is of vital importance to those on board the aircraft and to those concerned with the establishment and implementation of safety criteria.

The International Civil Aviation Organization (ICAO), a specialized aviation agency of the United Nations, is conducting continuing studies of airline pilot incapacitation.[98] These studies show that pilot incapacitation problems may occur at any time. In some cases, crashes have occurred as a result of the incapacitations. If the pilot collapses during a critical maneuver such as takeoff or landing, chances of a crash are greatly increased. This is particularly true for helicopters since the operating environment leaves little time for corrective action. The ICAO study shows that crashes caused by pilot incapacitations resulted in the loss of 148 lives during one 5-year period. These accidents were caused mostly by heart attacks occurring during high physiological stress. The FAA has predicted that approximately 3 in-flight pilot deaths can be expected per year among U. S. scheduled air carriers. Incapacitation of pilots flying military aircraft could also be caused from injuries received in combat areas. If the pilot collapses onto the flight controls and jams them, the problem is compounded because the copilot must remove him from the controls before he can assume command. Should this occur during normal flight, there is a very good chance that aircraft safety would not be seriously impaired and the main concern would be for the condition of the disabled pilot. If incapacitation should occur during one of the critical periods of a flight, there might not be sufficient time for the copilot to take command.

To minimize the likelihood of pilot collapse, the FAA and the airlines require frequent rigorous physical examination of all pilots. This is also true for pilots in the armed services. To further reduce incapacitation possibilities, the FAA is considering the addition of the Master's Test, a diagnostic test used to uncover previously undetected heart disease. No examination can guarantee the elimination of incapacitation. Therefore, effort must be concentrated on immediate removal of the disabled pilot from the controls or on preventing his

contact with the controls after incapacitation. Mechanical devices are under consideration to do both. These devices require that the pilot wear the shoulder harness attached to a standard inertia reel.

One approach involves the use of a gas generator with a power-retracting device attached to the inertia reel, which can be positioned so that it can be activated by any able crewmember. The reel would then haul the disabled pilot back into his seat and hold him there.

The medical department of one major airline has experimented with a design that involves the use of both a power inertia reel and a motorized seat to remove the pilot from the controls after incapacitation.

A third approach, called Disabled Pilot Restraint (DPR), has been proposed by an inertia reel manufacturer. According to a paper published by an employee of this manufacturer,[99] tests have shown that a small restraining force of approximately 10 pounds at the pilot's shoulders is sufficient to stabilize him and prevent further forward motion of his body in case he is incapacitated. Until it is engaged, the DPR has no effect and the interia reel performs normally. During more hazardous operations such as takeoff and landing, the DPR would be engaged. Upon engagement of the DPR, a friction force is applied to the shaft of the inertia reel and thus to the harness straps through an integral brake mechanism.

The restraining load increases by approximately 50 percent as the pilot leans forward in his seat. This increase in restraining load compensates for the increase in moment caused by the pilot moving away from the seat back. When the pilot's upper torso ceases to pull against the harness, the unidirectional brake allows the reel to rewind the harness straps in normal operation. If excessive acceleration forces occur at any time while the DPR is engaged, the inertia mechanism performs its normal function and locks, thus preventing any strap extension regardless of the DPR drag.

The integral brake mechanism is totally mechanical and can be controlled either electrically or mechanically. If desirable, the brake could be actuated remotely in a number of ways. For example, in the case of fixed-wing aircraft it could be actuated whenever the flaps were lowered for landing or takeoff. When the flaps are returned to the up position, the brake could be automatically deactivated.

Since this is not an attempt to evaluate the various methods of removing a disabled pilot from the controls, the advantages

or disadvantages of the three methods described briefly above are not discussed. The methods were presented to show that the power-retracting inertia reel is not the only approach under consideration for removing or restraining the incapacitated pilot from contact with the controls.

The question has been raised about the effect the power reel will have on a severely injured pilot (especially back injuries) during the process of hauling him back from the controls. Medical doctors indicated[97] that the slow reel-in velocity of the power reel will not worsen the pilot's condition, although there are no known cases where the power reel has been used to remove a disabled pilot from the controls of the aircraft.

Merit of the Device as a Means of Combating Occupant Dynamic Overshoot and Submarining

The computer program SIMULA was modified to permit superimposing the power-retracting inertia reel properties into the analysis. The results of this analysis were reported in the Variable Analysis section. This analysis concluded that the power-retracting inertia reel did not present any advantages over the standard inertia reel for the chosen restraint system concept. It is realized, however, that this might not be true for other restraint systems.

Human Factors Engineering

It has been established that if the occupant is properly positioned in the seat during a crash, he will be able to survive higher crash deceleration loads than would be the case otherwise. This is especially true for crash deceleration loads in the vertical direction. The primary reason the power reel is used with restraint systems in ejection seats is to prevent spinal injuries by properly positioning the occupant in the seat before ejection takes place. For the same purpose, the power reel was considered for use with nonejection seats. In the case of ejection seats, it takes about 0.30 sec to complete aircraft canopy jettison and an additional 0.05 sec to initiate seat-catapult ignition. During the next 0.03 sec, pressure builds up sufficiently within the catapult to cause first seat motion.[96] Therefore, approximately 0.38 sec is available for placing the crewman in his proper ejection position. In the case of nonejection seats, conditions are considerably different.

Since 9 ft/sec reel-in velocity is approximately the highest reel-in velocity that can be used without causing personnel injuries, increasing reel-in velocity will not make standard sensing systems acceptable.

Because of the inadequate state of development of predictive sensing systems, manual actuation prior to impact appears to be the only method available for timely operation of power inertia reels. Yet manual actuation of the power inertia reel leaves much to be desired in that the pilot's attention would be diverted to trying to avoid the crash and the actuation task probably would be neglected. Thus, manual control does not seem feasible.

At this time, human engineering problems associated with the power reel are considerably more complex than those associated with the standard reel; therefore, the standard reel presents advantages over the power reel in this regard.

Economics

The cost of the power reel is higher by a factor of 6 to 7 than the cost for the standard reel models in high quantity production runs. The cost ratio is higher for small quantities. The incorporation of a necessary crash detector system in the power-retracting inertia reel system will make it even more expensive. Post-impact crash sensors on the market today are relatively expensive, and a crash detector system would include several.

Poor economy, therefore, is one of the major disadvantages of the powered inertia reel.

Maintainability

The preliminary operating maintenance manual for a newly developed and qualified powered inertia reel system gives a very fair idea of the maintenance complications created by the additional components.[100]

In addition to the more cumbersome maintenance work required by the power reel, such components as the gas-operated initiator and the gas generator are quite dangerous to maintenance crews. An extra set of instructions for safe handling of these components is required. The standard inertia reel has the advantage of mechanical simplicity over the powered reel in the area of maintainability.

Reliability

Reliability problems of the power reel are very similar to those already described for the post-impact sensor.

Pisano's report,[99] under Reliability Assessment Analysis concludes that an attribute reliability of initiating, based on

56 successful firings, is at least 96 percent with 90 percent confidence. The assessment recommends that additional tests be conducted in cyclic environment and partial stroke and that these tests be accomplished with samples taken out of the first production lot.

Reliability cannot be demonstrated concurrently with development programs, and power reel systems are still under development. Development programs can provide information upon which to base reliability predictions, but demonstration of reliability should be based on performance of production items. Without large-quantity, long-term testing of production units, the level of reliability which the power reel system can provide can neither be fully demonstrated nor completely predicted. Lack of actual large-quantity, long-term testing in this area must be acknowledged.

Weight

The weight of a standard inertia reel, including the reel, strap, and metal end fitting, is 1.3 pounds. The weight of the power-retracting inertia reel, including the strap, reel, gas generator, and 14 inches of tubing, is 3.8 pounds. There are small variations in weight among the products of different manufacturers, but for identical systems, in general, the weight of the power reel is heavier than the standard reel by an approximate factor of 3.

Again, the standard reel presents an advantage over the power reel.

Service Life

Service life data for the power reel are very limited. Therefore, a direct evaluation of the service life of the power reel versus the standard reel cannot be made at this time.

The power-retracting inertia reel is formed around the standard reel by adding various components performing specialized functions. If it is assumed that these additional components will not adversely affect the service life of the power reel, then the service life of both reels will be the same. Therefore, under the most favorable conditions, service life for the power reel should be equal to that of the standard reel. Should these additional components have some adverse effect on the service life of the power reel, then the standard reel will present some advantage over the power reel in this area.

Conclusions

The use of a power-retracting inertia-reel system is not recommended for use with the nonejection seat restraint system at this time. Its doubtful usefulness and high cost, coupled with the unproven reliability of the system, do not justify its selection.

With the development of adequate and cost-competitive sensing systems, acquisition of favorable reliability data, and reduced production costs, and when systems can be used to preposition the seat occupant advantageously to withstand the major crash pulse, their use should again be evaluated.

DESCRIPTION OF RESTRAINT SYSTEM

The end-item, System, Aircrew, Forward Facing, consists of a single-point release buckle and tie-down assembly, left- and right-hand lap-belt assemblies including side straps, left- and right-hand lower shoulder harness straps, a shoulder harness collar assembly, and two reflected inertia reel straps.

The harness assembly mounts on an air crewman's forward-facing seat as shown in Figure 67. The buckle assembly consists of a single-point release buckle connected permanently through a fitting to the tie-down strap assembly. The tie-down strap assembly consists of a double strap of fixed length for any seat and cushion design. This strap connects beneath the cushion to the seat pan by a bolted fitting. Left- and right-hand lap-belt assemblies connect to a single-point release buckle. The lap-belt assemblies include both a lap belt and a side strap. The lap belts are connected to the seat or aircraft structure through automatic lock-unlock retractors. The side straps connect to the seat structure through combination adjuster/anchors. The lower shoulder harness connects into the bottom of the collar assembly through adjusters. The collar assembly consists of a pad, in the form of a collar, that fits around the occupant's neck. The harness straps are routed over this collar. Roller fittings are attached to the collar near the top of the shoulders. The collar assembly is attached to the seat by means of two reflected straps and an inertia reel. Each strap extends forward from the inertia reel and is routed around the roller fitting and back to the opposite side of the seat back. This strap is attached to the seat through a fitting on the reflected end and through an inertia reel at the other end. The lap-belt assemblies, tie-down strap assembly, and lower shoulder-strap assemblies are connected at a single-point release buckle.

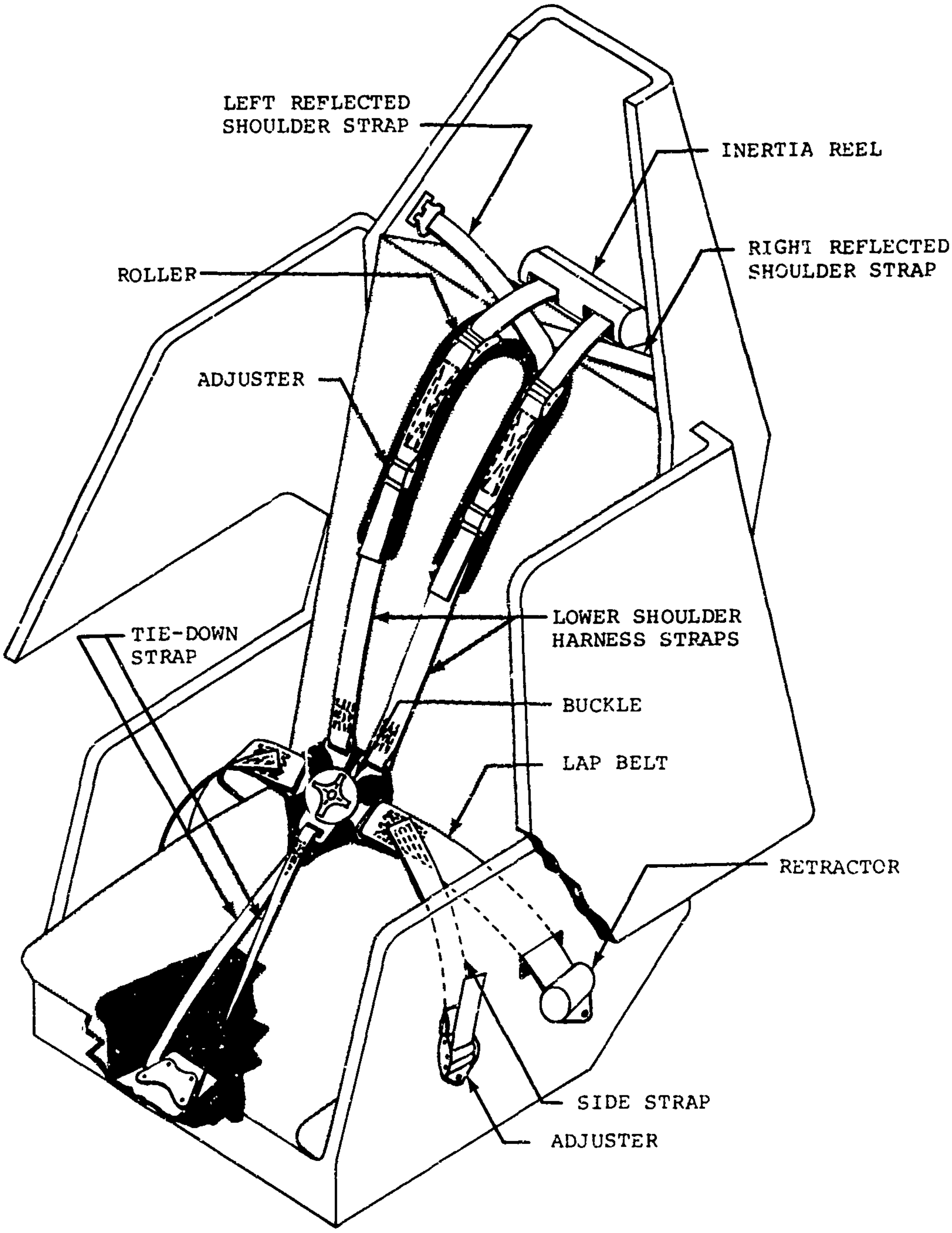


Figure 67. Optimum Restraint System Concept.

Since hardware components meeting specification requirements were not available for system proof tests, certain substitutions were made. The tested restraint systems are discussed in the Proof Testing Section of this report.

PROOF TESTING

The prototype restraint system was designed to comply as closely as possible with the preliminary restraint system specification. Certain components, such as buckles, adjusters, roller fittings, and retractors capable of complying with the desired specifications, were not commercially available. Consequently, it was necessary to evaluate and use components which did not completely comply with the specification, but which would be adequate for evaluation of the overall restraint system design. It was necessary to substitute Military Standard hardware in some locations and to use custom-made hardware in others. For example, a buckle simulator was fabricated and used since a single-point rotary buckle meeting the strength requirements was not available from industry.

Six static tests were performed to evaluate the lap belt, shoulder harness, and tie-down straps. Attachment and adjustment hardware associated with each component was tested along with the component. Prior to each test, the component was adjusted to the length required for a 95th percentile occupant.

Five additional static tests of force versus percent elongation were conducted on various types of polyester webbing and on the specially made 2-1/4-inch-wide polyester webbing which had been selected for the lap belt.

One dynamic test was performed. The restraint system was used to secure a 95th percentile anthropomorphic dummy equipped with helmet, body armor, vest-type survival kit, and associated components to a simulated seat. The dynamic test loaded the restraint system in the longitudinal direction with the simulated seat rotated to induce a lateral load component.

The results of the static tests established the failure loads of the restraint system components and associated hardware. The dynamic test provided acceleration-time histories for the occupant and measurements of the pertinent forces developed in the restraint system. The dynamic test also demonstrated system performance and furnished empirical data necessary to evaluate all aspects of the personnel restraint system.

DESCRIPTION OF RESTRAINT HARNESS

The test article was a personnel restraint system for a forward-facing, nonejection seat. The prototype restraint system conformed with the preliminary restraint system specification and had the general features required for efficient occupant crash protection for use in Army aircraft.

The initial restraint system used in the static tests is shown in Figure 68. The restraint system consisted of a lap belt with side straps, a double-strap lap-belt tie-down, and a shoulder harness incorporating the reflected strap approach. Restraint system components were attached through a single-point release buckle.

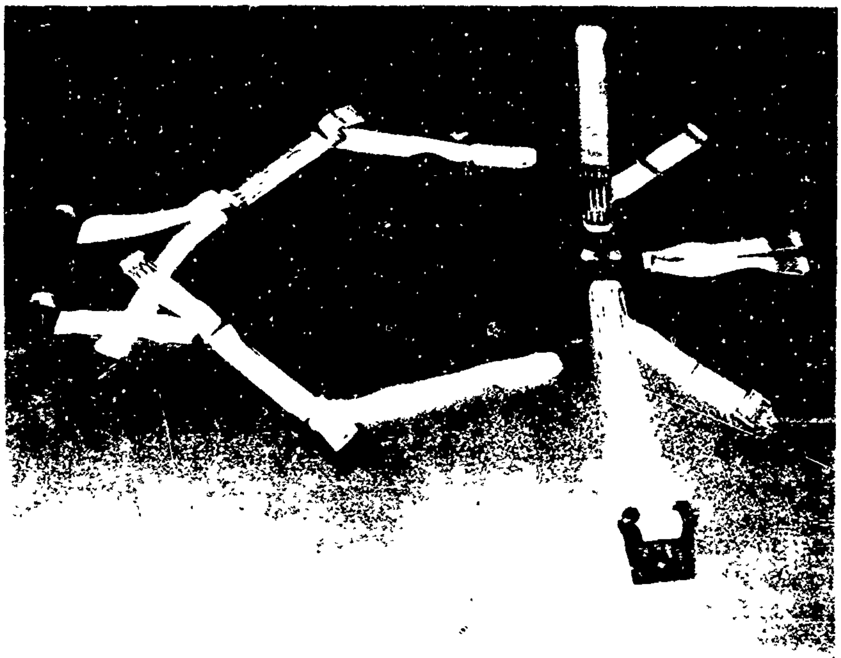


Figure 68. Initial Static Test Restraint System.

The lap belt was fabricated from specially made 2-1/4-inch-wide polyester webbing per MIL-W-25361B, except for the weave pattern which was in accordance with MIL-W-4088F, Type XXVIII. It was anchored to the seat by prototype devices that simulated manual lock-unlock retractors (shown in Figure 69) and connected to the single-point release buckle through connectors. The side straps were fabricated from MIL-W-25361B polyester webbing, Type I. They were permanently sewn to the lap belt and attached to the seat through an MS70116 quick-release link. A spring was added to position the locking bar tightly against the webbing. The modification enabled these fittings to be used as adjusters for taking up the side-strap slack.

The double-strap lap-belt tie-down design required a fixed length for any given seat configuration, thus positioning the

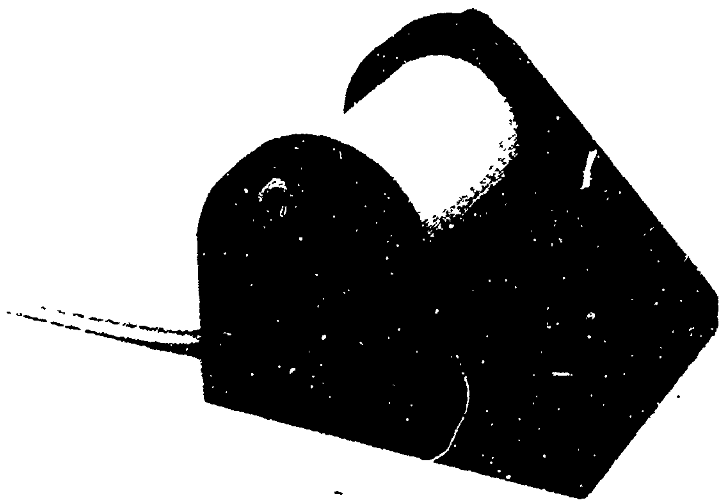


Figure 69. Prototype Lap-Belt Retractor.

buckle at a given height above the seat reference point. The test tie-down strap was made from nylon fabric per MIL-W-4088F, Type XXV (modified to a 1-1/4-inch width). Load spreader back-up padding for use with the single-point release buckle and the horse collar used under the shoulder harness were made from 3/16-inch-thick Ensolite, shock-absorbing type AL, covered by blue 0.032-inch-thick virgin vinyl.

Shoulder harness adjusters and roller guides were connected with polyester webbing per MIL-W-25361B, Type II. The webbing in turn was permanently sewn to each side of the horse collar (shoulder harness padding). The adjusters, per MS2207, were attached at the lower end of the webbing on the horse collar on each side of the chest area as shown in Figure 68. These adjusters were necessary in order to fit different percentile occupants. The lower straps of the shoulder harness passed through the adjusters, connecting to the single-point release buckle through connectors. The lower straps were fabricated from polyester webbing per MIL-W-25361B, Type II.

MS22021 removable parachute connectors were modified and used as guide rollers. The guide rollers were attached on each side of the horse collar at the shoulder-neck area. The reflected straps, made from polyester webbing per MIL-W-25361B,

Type II, passed through these guide rollers as shown in Figure 70. The webbing from one inertia reel located toward the left side of the seat passed through the guide roller attached on the left side of the horse collar and was fastened on the right side of the upper structure of the seat back. In a similar manner, the webbing from the right side inertia reel passed through the right side roller and was fastened on the left side of the seat back. Two single inertia reels per MIL-R-8236C, Type MA-6, were used. MS27760 lug assemblies were used for the reflected shoulder strap tie-downs.

Figure 70. Reflected Strap and Roller Fitting.

STATIC TESTS

Test Environment

Test fixtures were designed and fabricated so that each of the restraint harness components being tested, together with the associated connecting and/or attaching hardware, had one end attached to the fixed end of a tensile tester through the load cell and the other attached to the moving platform. The tensile tester was also used for the force-versus-percent-elongation static tests performed on the various types of

polyester webbing. The webbing was mounted in test position on the tensile tester through a set of split-drum-type test jaws. These jaws were fabricated according to Natick Laboratories Specification Drawing 2-1-767.

The static tests of the lap-belt assembly were conducted using a platform to assure that the belt assembly was aligned at all times with the loading force. Test fixtures were designed and fabricated for attachment of the lap-belt retractors and side strap adjusters. One of these test fixtures was fastened to the platform to restrict linear and rotational motion, and the other fixture was attached to the piston of a hydraulic cylinder attached to the other end of the platform. The hydraulic cylinder was fastened on the platform to allow the piston side of the cylinder to move laterally during the test. All test fixtures were designed and fabricated so that a pure tensile load would be applied to the component being tested.

Component Tests

A 10,000-pound load cell designed to measure tensile loads was used for the static tensile tests. A pointer was attached to the moving platform and referenced to a scale positioned along the platform path of travel. Elongation of the component being tested was visually monitored during the test and at failure. The load cell readings were recorded on a direct-write oscillograph.

The load cells are calibrated to National Bureau of Standards requirements.

The components of the restraint harness were mounted in the test apparatus and an initial load of approximately 100 pounds was applied to eliminate the slack from the system. At this point, the displacement of the test components was checked to establish the zero reference for elongation measurements. The load was then increased until the component failed. The loads and elongation of each component were recorded at design and failure loads.

Webbing Tests

Five static tests of polyester webbings were conducted in accordance with FED-STD-191 test method 4108.1 to determine force-percent elongation. The test specimen in four of the tests was a single 54-inch length of webbing. The test specimen for the fifth test consisted of two 54-inch lengths mounted side by side in the test jaws.

The test jaws were of the split-drum type, and the distance between the clamps (gage length) was 10 ±1/2 inches center-to-center. Two marks spaced 5 inches apart were inked on the specimens. The marks were placed so that neither was closer than 1-1/2 inches to each clamp when the specimen was mounted in the clamps.

To determine elongation, the movement of the tensile tester platen was stopped at load level increments of 1000 pounds and at 90 percent of the minimum breaking strength, and the distance between the ink marks was measured. Webbings tested were Type II, Type III, and Type IV, per MIL-W-25361B and the specially constructed 2-1/4-inch-wide webbing which conforms with MIL-W-25361B except for the weave pattern which is per MIL-W-4088F, Type XXVIII. Webbing per MIL-W-25361B, Type II, was used for the test in which the two lengths were mounted side by side.

Figures 71 through 79 show the various webbings mounted on the tensile tester at the beginning and last readings for each test.

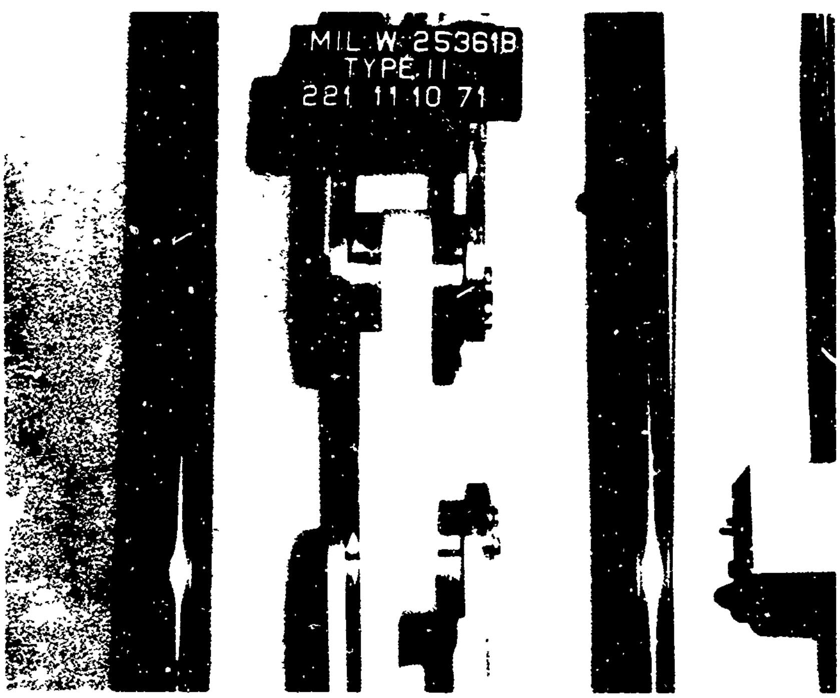


Figure 71. Type II Webbing Under 100-Pound Load.

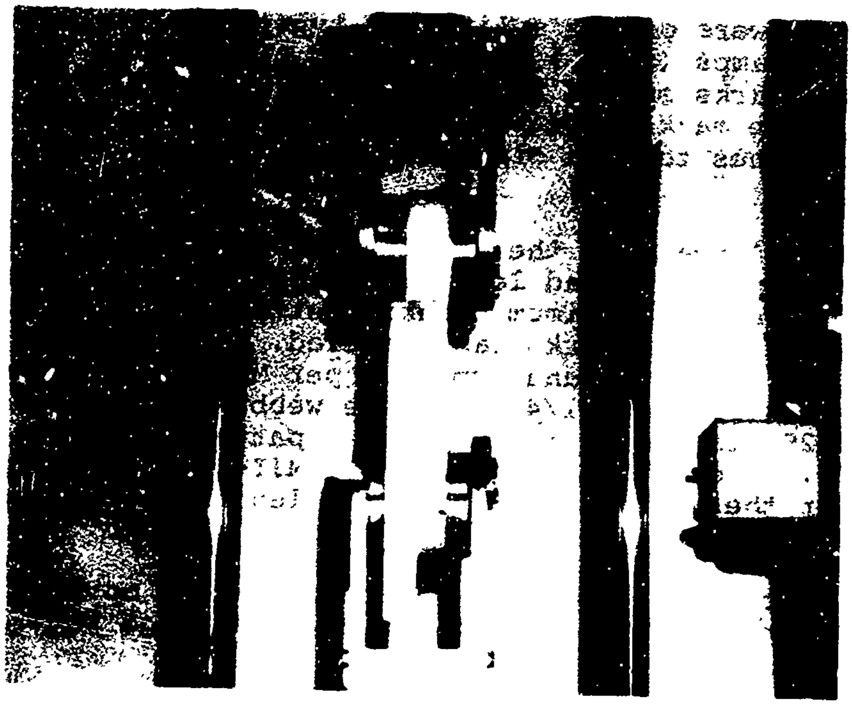


Figure 72. Type III Webbing Under 100-Pound Load.

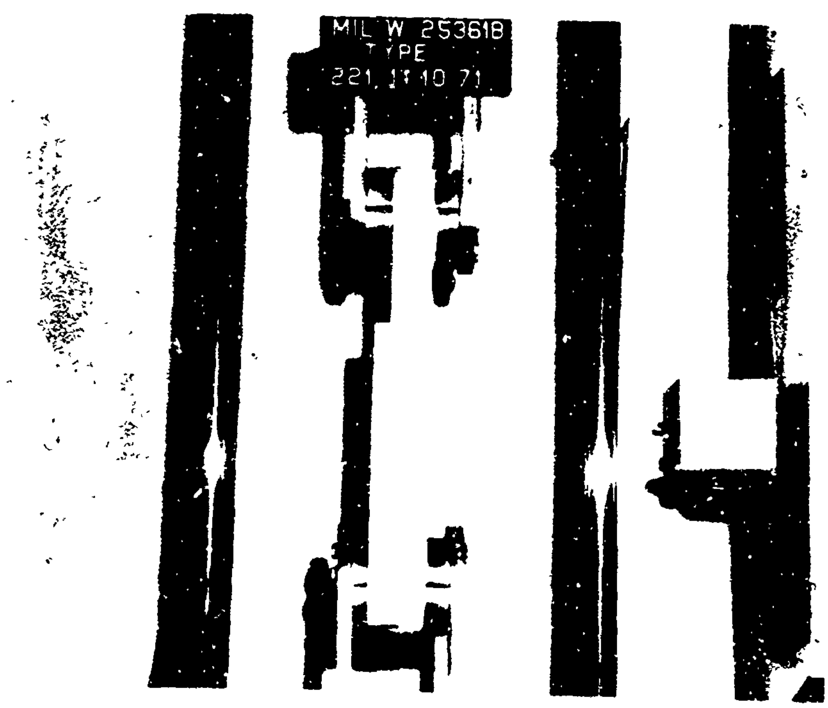


Figure 73. Type III Webbing Uncer 6800-Pound Load.

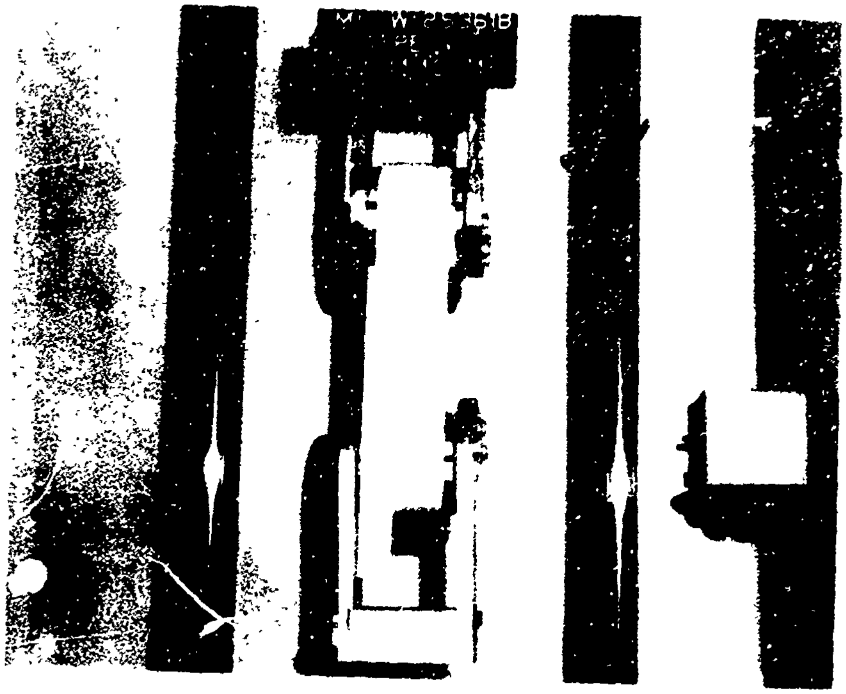


Figure 74. Type IV Webbing Under 100-Pound Load.

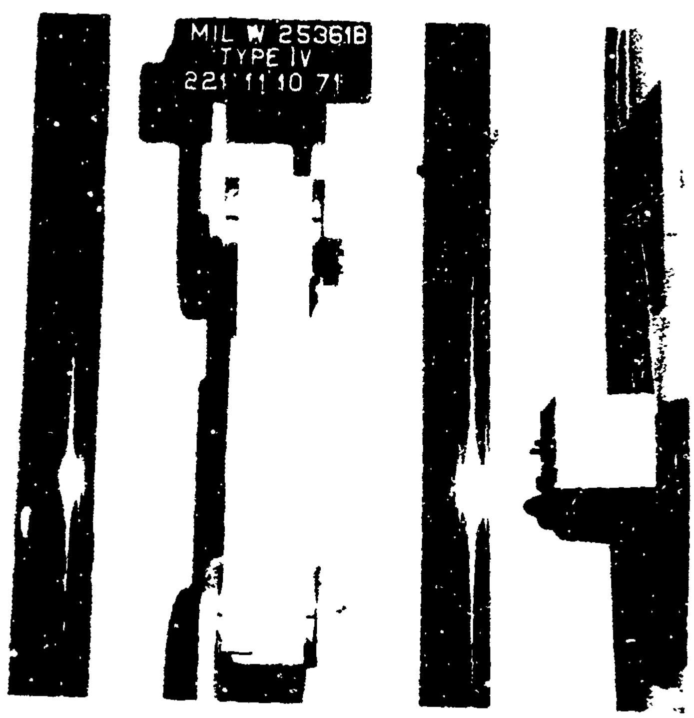


Figure 75. Type IV Webbing Under 7800-Pound Load.

Figure 76. Special Lap-Belt Webbing Under 100-Pound Load.

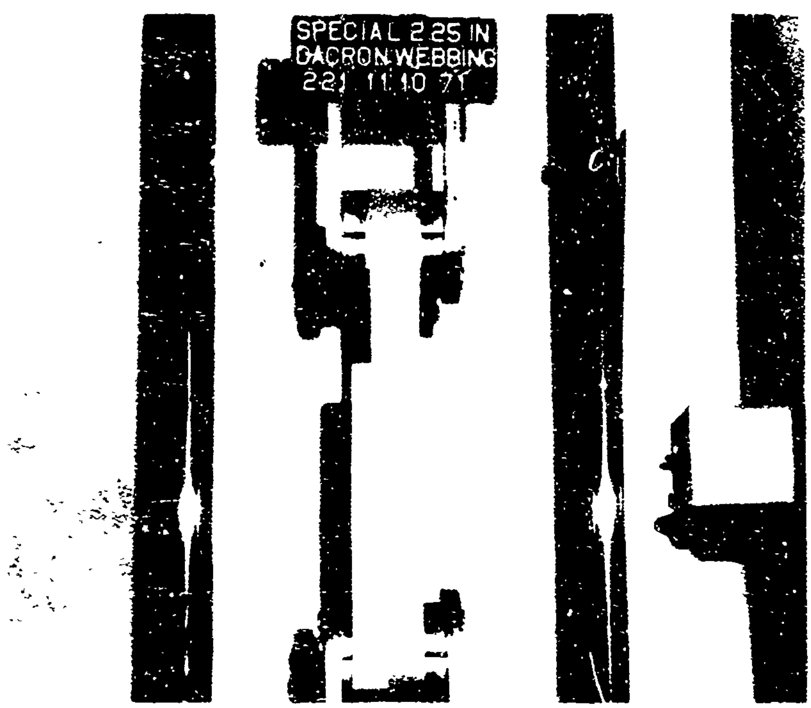


Figure 77. Special Lap-Belt Webbing Under 8000-Pound Load.

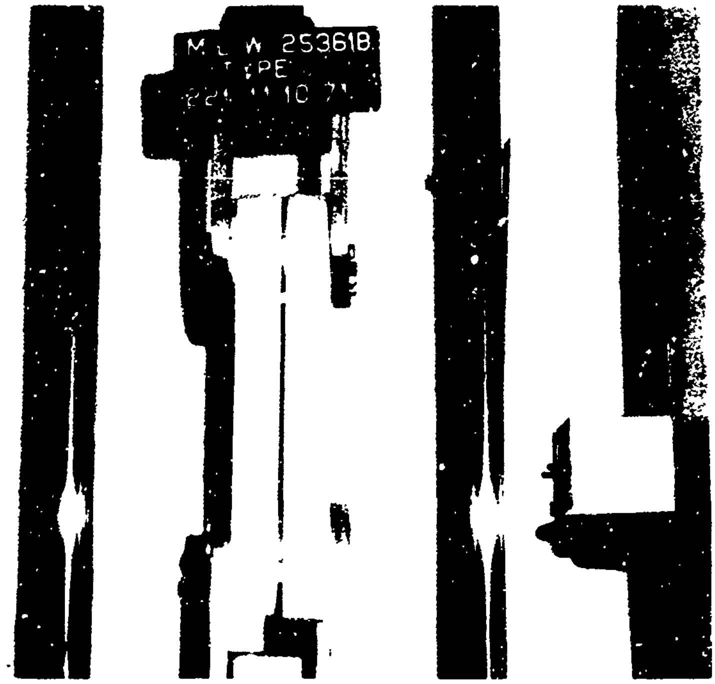


Figure 78. Two Straps of Type II Webbing Under 100-Pound Load.

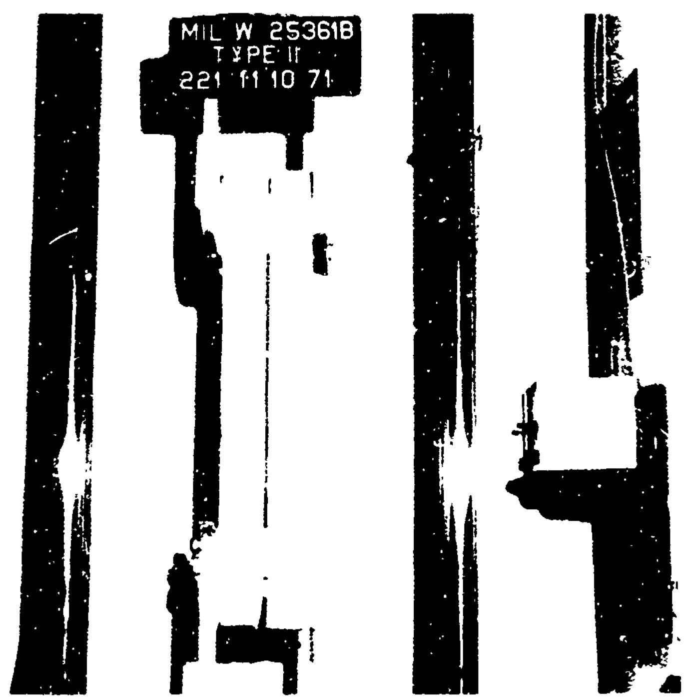


Figure 79. Two Straps of Type II Webbing Under 5500-Pound Load.

Static Test Results

Test 1 - Double-Strap Lap-Belt Tie-Down

Figure 80 shows the double-strap lap-belt tie-down mounted on the tensile tester under a load of approximately 100 pounds. Figure 81 shows the double strap after the test with the buckle connector which failed at 2845 pounds. Total elongation at failure was 1.875 inches.

Tests 2 and 3 - Shoulder Harness

Test 2 was conducted on the lower shoulder harness. Figure 82 shows the strap mounted on the tensile tester under a 100-pound tensile load. Figure 83 shows the lower shoulder-harness strap after the test. The webbing failed at the buckle connector. This failure occurred at 3640 pounds tensile load. The total elongation at failure was 2.313 inches, and elongation at design load of 2000 pounds was 1.25 inches.

Figure 87 shows the reflected strap mounted on the tester under a 100-pound tensile load (Test 3). The reflected strap after failure of the webbing at the adjuster is shown in Figure 85 The webbing failed at 5302 pounds tensile load; total elongation at failure was 3.375 inches. Elongation at design load of 2000 pounds was 1.125 inches.

Test 6 verified the results of Test 3.

Tests 4, 5, and 7 - Lap Belt

The right half portions of two different lap-belt configurations were evaluated (Tests 4 and 7) in addition to a complete lap-belt assembly (Test 5).

Figure 86 shows the right side of the lap belt mounted on the tester under a 100-pound tensile load (Test 4). This lap belt was the original configuration with the custom-made buckle connector without the side-strap adjusters. Figure 87 shows the lap belt after the buckle connector failed at 4900 pounds tensile load. Elongation at design tensile load of 4000 pounds was 2.563 inches, and total elongation at failure was 3.187 inches.

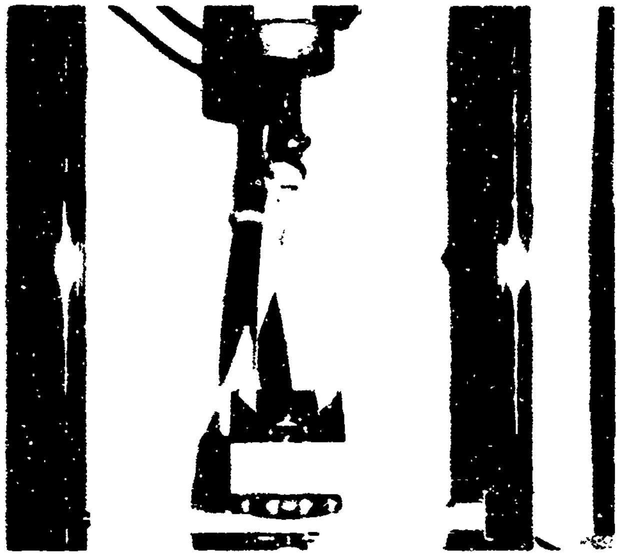


Figure 80. Double Strap Lap-Belt Tie-Down
Under 100-Pound Tensile Load.

Figure 81. Double Strap After Failure
of the Buckle Connector.

Figure 82. Lower Shoulder-Harness Strap Under 100-Pound Tensile Load.

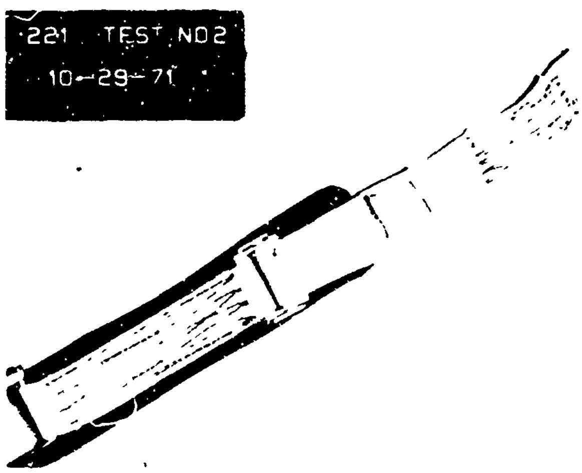


Figure 83. Lower Shoulder-Harness Strap After Failure.

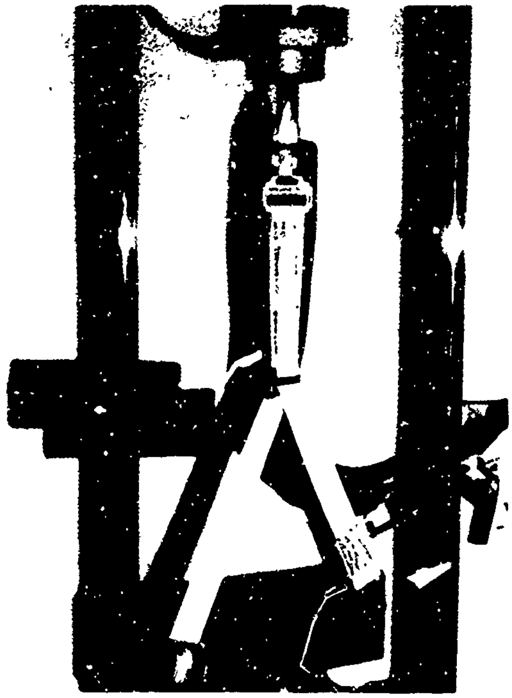


Figure 84. Reflected Strap Under 100-Pound Tensile Load.

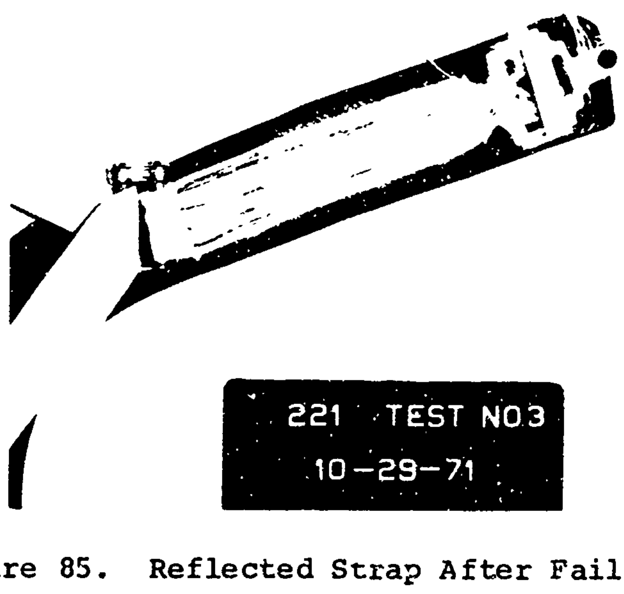


Figure 85. Reflected Strap After Failure.

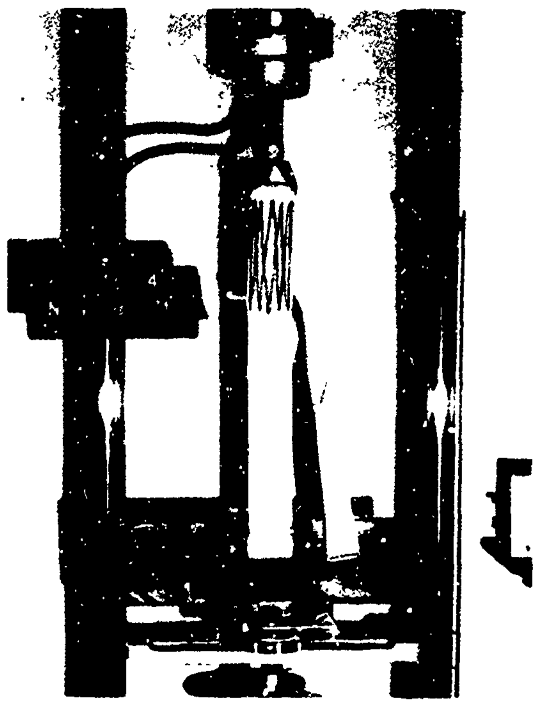


Figure 86. Right Side of Lap Pelt Under 100-Pound Tensile Load.

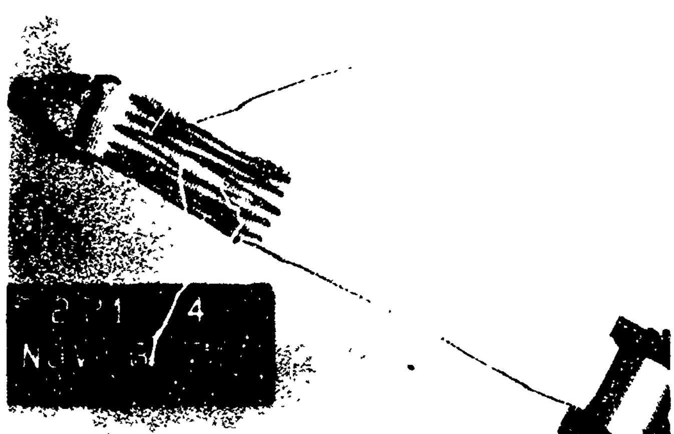


Figure 87. Lap Belt After Failure of Buckle Connector.

For Test 5 the entire lap-belt assembly was mounted on the test platform under a 100-pound tensile load (Figure 88). Buckle failure occurred at 2760 pounds tensile load as shown in Figure 89. Total elongation at failure was 3.625 inches. Figure 90 shows the failed buckle.

The test fixture was designed so that, when a tensile load of 4000 pounds was acting on the lap belt, a load of 1500 pounds was exerted on the side straps. The side strap adjusters did not perform adequately in this test because the webbing slipped through the adjusters. This can be seen by comparing the length of the free part of the side strap in Figures 88 and 89. The free part of the webbing in Figure 88 is longer than in Figure 89, indicating that the side strap not only stretched due to the tensile load applied but also slipped.

In an effort to reduce the elongation of the lap belt, it was decided to use a double-strap lap belt. The configuration of this lap belt is the same as described earlier in this report except that a double strap was used. The double configuration is shown in Figure 91 installed on the prototype retractor spool.

The results of the double-strap lap-belt tie-down assembly static test indicated that, in order to obtain the required tie-down loads, the buckle connectors had to be replaced by higher strength units. Connectors made from low carbon alloy steel (AISI 4130) heat treated up to 180,000 psi ultimate tensile strength were substituted and used throughout the remaining tests.

Figure 92 shows the right side of the double-strap lap-belt configuration mounted on the tensile tester under a 100-pound tensile load (Test 7). Total elongation at the design load of 4000 pounds tensile load was 2.0625 inches.

Table XXXIII presents a data summary of the static tests performed on the lap-belt assemblies. The percent elongation for the components was calculated using the lengths and the total elongation at design and failure load shown in the table.

Tests 8 Through 12 - Webbing Elongation Tests

The results of the force-percent elongation tests are plotted in Figure 93.

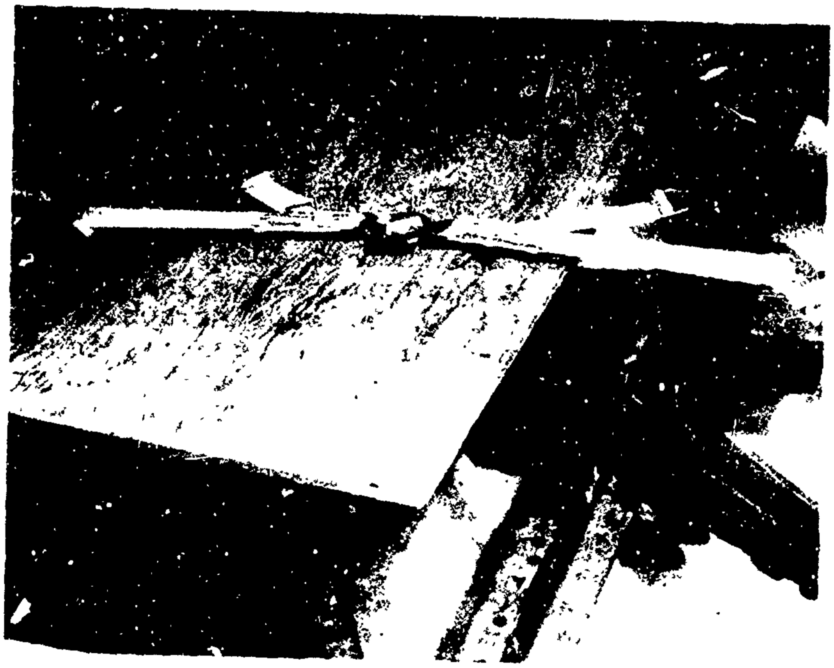


Figure 88. Lap-Belt Assembly Under 100-Pound Tensile Load.

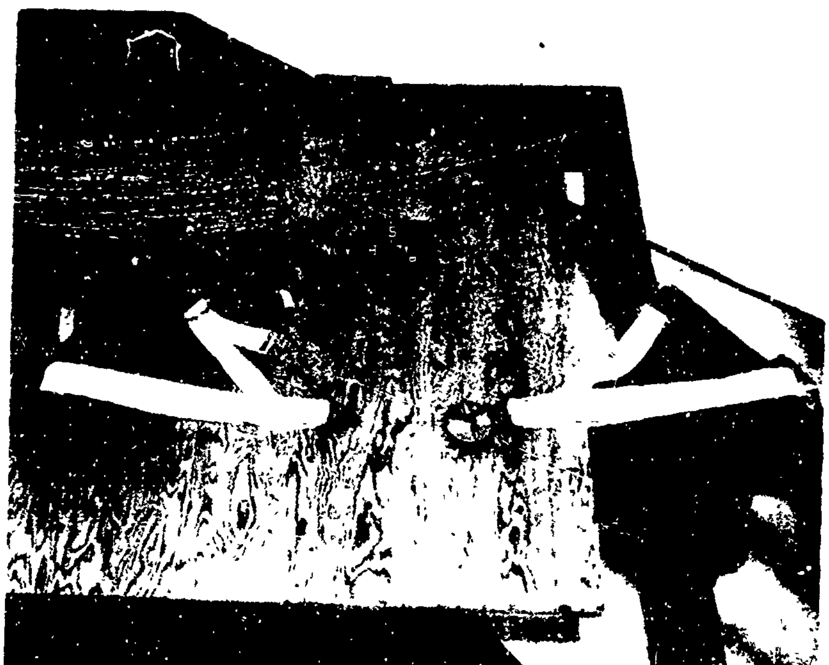


Figure 89. Lap-Belt Assembly After Failure of Buckle.

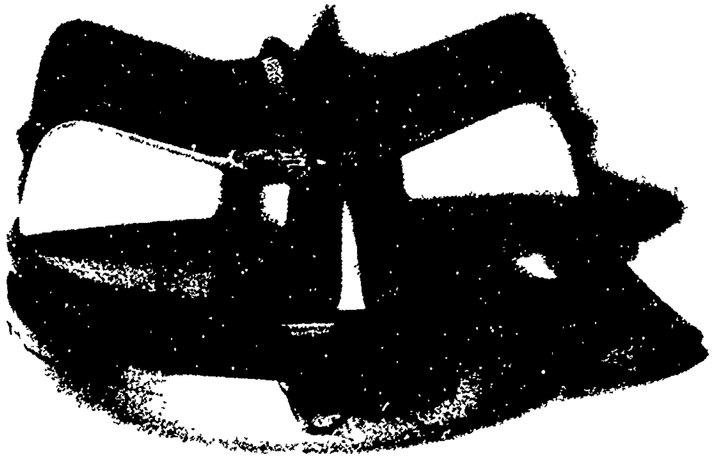


Figure 90. Failed Buckle.

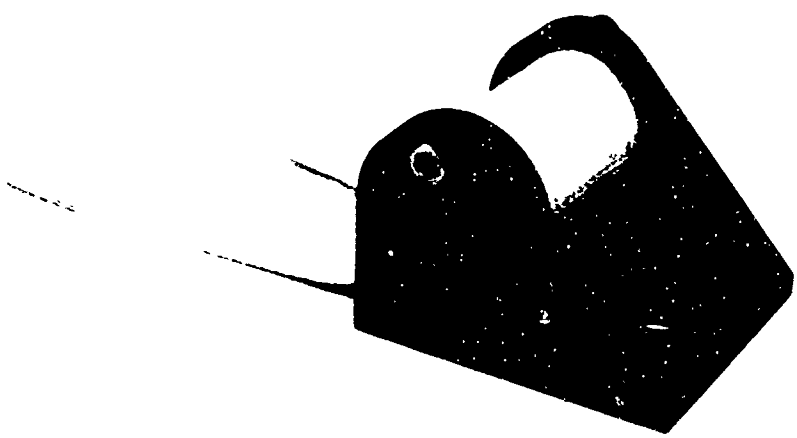


Figure 91. Double-Strap Lap Belt Installed.

Figure 92. Double-Strap Lap Belt Under 100-Pound Tensile Load.

TABLE XXXIII. SUMMARY OF STATIC TESTS ON RESTRAINT HARNESS COMPONENTS

Test No.	Test Description	Failure Component	Failure Load (lb)	Length of Test Component (in.)	Elongation at Design Load: Load (lb)	Elongation at Design Load: Total (in.)	Elongation at Design Load: Elongation (pct)	Elongation at Failure: Total (in.)	Elongation at Failure: Elongation (pct)
1	Double-Strap Lap-Belt Tie-Down	Buckle Connector	2845	8.5	2500	1.28	21.0	1.875	22
2	Lower Shoulder Strap (Chest Strap)	Webbing at Buckle Connector	3640	12	2000	1.25	10.4	2.313	19
3*	Reflected Strap	Webbing at Adjuster	5302	24	2000	1.125	4.7	3.375	14
4	Half Lap Belt (Single Strap)	Custom Buckle Connector	4900	16.5	4000	2.563	15.5	3.187	19.3
5	Entire Lap-Belt Assembly (Single Strap)	Buckle	2760	41.7**	4000	NA	NA	3.625	9.93
6	Half Lap Belt (Double Strap)	-	-	16.5	4000	2.0625	12.5	-	-

*Verified in Test 6.
**From the total length of the lap-belt assembly of 41.7 inches, the length of the buckle diameter and connectors (5.25 inches) is subtracted for the percentage elongation calculation.

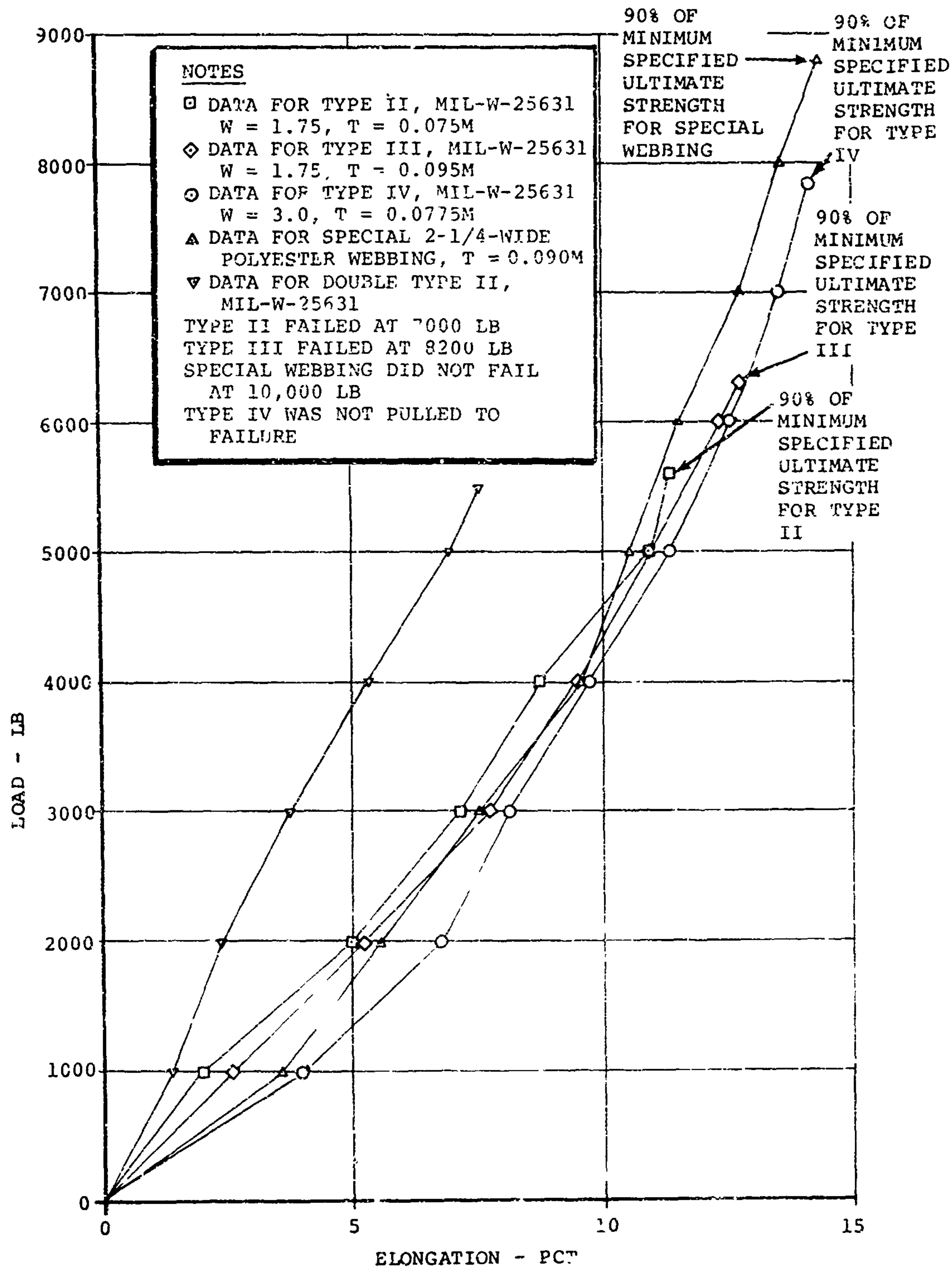


Figure 93. Results of Force Versus Percent Elongation Tests.

The Type II and Type III webbings were pulled to failure which occurred at 7000 and 8200 pounds tensile load, respectively. The special webbing was loaded to the 10,000-pound capacity of the tensile tester, but did not fail. Type IV was pulled to 90 percent of its minimum ultimate strength.

Discussion of Static Test Results

The elongation of the lap-belt tie-down double assembly was considerably higher than the design requirement of 0.5 inch because the webbing material was nylon, which, in general, has higher elongation than polyester. This webbing was used as a substitute since it was the only webbing available conforming to width and thickness requirements established for the developed restraint system. Polyester webbing 1-1/4-inch-wide that meets military specifications was not available.

The webbing required in the specification for the lap-belt tie-down application will have force-percent elongation characteristics similar to Type II per MIL-W-25361B. From Figure 93, the data from the double strap Type II per MIL-W-25361B test indicates a 3.15-percent elongation at a 2500-pound load. The elongation of the specified double-strap lap-belt tie-down at design load will be (8.0)(.0315) = 0.262 inch, which is well within the design requirement of 0.5 inch.

The relatively low load at which the buckle connector failed can be attributed to its fundamental design which permits the development of high bending loads. This can be verified by examination of the failed part and also by comparison with the lower shoulder-harness-strap buckle connector. The lower shoulder-harness-strap connector survived loads up to 3640 pounds where the webbing failed. The overall length of the lower shoulder-harness-strap buckle connector is greater than the double-strap lap-belt tie-down connector. This helps reduce the intensity of the bending load in the critical areas.

During both Test 2 (lower shoulder-harness strap) and Test 3 (reflected strap), the webbing failed in the same manner at the interface with the piece of hardware (buckle connector and adjuster). The difference in the magnitude of the failure load is significant,however, and this again is due to the design of the hardware. The opening of the buckle connector for the connection with the lower shoulder-harness-strap webbing is about 1-1/4 inches long. This requires that about 1/4 inch of webbing must be folded under on each side in order to connect the 1-3/4-inch-wide webbing. Examination of the failed part (Figure 83) shows a fairly clean cut across the webbing; however, the cut in the folded part of the webbing appears to have

been made by a knife. Inspection of the webbing indicates that failure started in the material that was folded under and progressed to the rest of the webbing. The edge of the hardware interfacing with the webbing was not smooth and straight but was relieved on each end to apparently provide room for the folded webbing edges; this also could have affected the initiation of the cut. It was concluded that folding and, in particular, folding of only a portion of the width of the webbing at its interface with the particular end fittings, should be avoided to preclude premature failure of the webbing.

The failure load for the lower shoulder-harness-strap test was 3640 pounds. The failure load for the reflected strap was 5302 pounds, an increase of about 45 percent from the lower shoulder-harness-strap failure load. The opening for the webbing connection of the adjuster (MS22007) is 1-3/4 inches long, which permits a connection with the 1-3/4-inch-wide webbing without folding. Examination of the failed part (Figure 85) shows a failure of the type occurring during an ultimate webbing strength test in the tensile tester, essentially indicating that the webbing failed simultaneously.

At the design load of 2000 pounds, the total elongation of the lower shoulder-harness strap and the reflected strap is shown to be 1.250 + 1.125 = 2.375 inches (see Table XXXIII). This elongation is in excess of the design requirement of 1.5 inches. There are two reasons for this. The first is that the elongation of the webbing permanently sewn on the horse collar is counted twice, since it was included in both subassembly tests from which the total elongation was calculated. The second reason is that approximately 16 inches of the webbing was rolled on the spool in the inertia reel and contributed to the total elongation through both elastic elongation and by compacting on the spool.

The elongation of the webbing permanently sewn on the horse collar was not separately measured; therefore, the total elongation could not be corrected for this effect. An estimate can be obtained, however, by examining the data in Table XXXIII for the lower shoulder-harness strap. The 10.4-percent elongation was calculated assuming that only the length of the lower shoulder-harness strap (12 inches) elongated, which was not entirely true. The data in Figure 93 for Type II webbing show that the elongation at 2000 pounds should be 5 percent. If it is assumed that the 8 inch-long webbing permanently sewn on the horse collar elongated in the same proportions as the lower shoulder-harness strap, then the percent elongation would be 1.25/20 = 6.25 percent, which shows better agreement with the data of Figure 93. This assumption, however, is not

exactly true because this webbing was looped and could not elongate in the same proportion as the single lower shoulder-harness strap.

Assuming that both components did elongate proportionately, the elongation counted twice would be (8.0)(.0625) = 0.5 inch. Subtracting this amount from the total elongation produces 2.375 - 0.50 = 1.875 inches, which is still somewhat higher than the design requirements.

Still assuming that 0.5 inch of the elongation was due to the horse collar webbing, the elongation of the reflected strap alone would be 1.125 - 0.5 = 0.625 inch. The geometry of the reflected strap has been idealized as shown in Figure 94. Actual geometry of the reflected strap will not change the final results, but it will make the calculations somewhat more tedious.

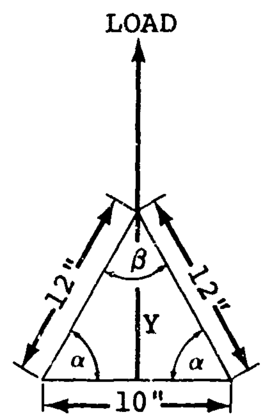


Figure 94. Geometry of Reflected Strap at Zero Load.

From Figure 94,

$$Y = \sqrt{144 - 33} = \sqrt{111} = 10.53 \text{ inches}$$

$$\cos \alpha = \frac{5.75}{12} = 0.479 \text{ and } \alpha \approx 61^\circ$$

Then,

$$\beta/2 = 180^\circ - 90^\circ - 61^\circ = 29^\circ$$

From Figure 95, the length of the reflected strap at 2000 pounds increased by $L_f - L_i$ is

$$L_f = \sqrt{(Y + 0.625)^2 + (5.75)^2} = 12.53 \text{ inches}$$

or, an increase in length of 2(12.53 - 12) = 1.06 inches, which corresponds to an elongation of 1.06/24 = 4.42 percent.

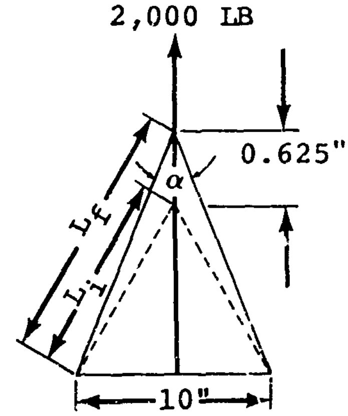


Figure 95. Geometry of Reflected Strap at 2000 Pounds.

The load through the reflected straps at 2000 pounds total loading is

$$F = \frac{2000}{\text{Cos } \gamma/2} \Big/ 2$$

and

$$\text{Cos } \gamma/2 = \frac{11.155}{12.53} = 0.890$$

Then,

$$F = \frac{2000}{0.89} \Big/ 2 = \frac{2250}{2} = 1125 \text{ pounds.}$$

From the data in Figure 93, Type II webbing elongates about 2.5 percent at 1125 pounds. Based on this percentage elongation, the reflected strap should elongate (24)(0.025) = 0.6

inch. If this is the case, the horse collar webbing would elongate more than the previously calculated 0.5 inch. This is very unlikely since the 0.5-inch elongation calculation for the horse collar webbing should have been on the high side.

Assuming that the length of the 16-inch webbing rolled around the spool inside the inertia reel contributed to the elongation in the same proportion as the free length, the elongation of the reflected strap would be (U_S) (0.025) where U_S represents the total length of the reflected strap. The total length of the reflected strap was 40 inches (24 inches from the spool centerline to the tie-down fitting and 16 inches rolled around the spool). Therefore, (40)(0.025) = 1.0 inch, which is very close to the 1.05 inches previously calculated. This indicates that the webbing rolled on the spool inside the inertia reel also contributed to the elongation of the reflected strap and therefore to the shoulder harness assembly.

The failure load of 4900 pounds for the custom-made buckle connector was almost twice the failure load of the regular buckle connector (2845 pounds) although the type of failure was very similar. Examination of the components after failure (Figure 87) showed that, had the buckle connector been a little stronger, the webbing would have failed in a manner very similar to the webbing of the lower shoulder-harness strap. Figure 87 clearly shows that the folded edges of the webbing are already cut, substantiating the assertion that folding the webbing through the lower-shoulder-harness-strap connectors decreased its load-carrying ability. The results of Tests 2 and 4 indicate that folding of the webbing through thin fittings should be avoided.

The percent elongation shown in Table XXXIII for Test 4 was calculated based on a webbing length of 16.5 inches, which was the length from the centerline of the retractor spool to the buckle connector. Calculating the percent elongation and considering 9.25 inches of webbing wrapped around the spool produces an elongation of 2.563/(16.5 + 9.25) = 2.563/25.75 = 9.97 percent. This percentage elongation compares very well with the data shown in Figure 93 for the special 2-1/4-inch-wide webbing at 4000 pounds. This indicates that the webbing wrapped around the spool in reels and retractors elongates and adds to the statically measured free component elongation. It is believed that the apparent elongation associated with elastic deformation and compaction of webbing rolled on spools is not elastically reversible in dynamic loading cases because of friction between webbing plies. Thus, this elongation is not thought to be detrimental to the performance of the system and may actually be beneficial by providing an energy-absorbing stroke.

The length of the lap-belt assembly in Test 5 was 41.7 inches. The buckle failed at 2760 pounds. Inside the buckle there are five pawls, each holding one of the five connectors (one from the tie-down strap, two from the lap belt, and two from the lower shoulder-harness straps). During this test, only the two pawls for the lap belt were in operation. Failure occurred by pulling one of the pawls out of the buckle and, in the process, breaking the buckle housing, indicating insufficient buckle strength. Also, during this test, the side straps slipped through the modified adjusters, indicating insufficient gripping strength of the adjuster on the thin webbing used.

In an effort to reduce the elongation of the lap belt, and considering the load-elongation data in Figure 93, it was decided to use a double strap for the lap belt. Test 6 was conducted to check the elongation of the lap belt with the double strap. The percent elongation shown in Table XXXIII is based on the length of 16.5 inches and is considerably different from the data in Figure 93. The total length of the half lap belt was 21 inches, since 4.5 inches was wrapped on the retractor spool during the test. Considering the 21-inch length to calculate the percent elongation results in 2.063/21 = 9.83 percent, which is still considerably higher for the load than the data of Figure 93 which is at least partially due to uneven loading of the two layers of webbing wrapped around the spool. Most of the loading was probably being taken by the outside layer. The 4000-pound tensile load is very close to the failure load of the custom-made buckle connector, suggesting that some elongation might be due to the connector; however, the elongation of the connector is not significant because of the relative stiffness of connector material compared to webbing. Examination of the test component revealed that a cut had been initiated on the folded ends of the webbing which may have added to the measured elongation.

Static tests (8 through 12) were performed on the various types of polyester webbings to check certain information received earlier from webbing manufacturers regarding the static force elongation characteristics of the webbings. This information indicated that the force-versus-percent-elongation curves for Types II, III, and IV per MIL-W-25631 are practically identical in the vicinity of the design loads. The data obtained from these tests (plotted in Figure 93) verify the information received from the webbing manufacturers.

Considering the results of Test 5 of the lap-belt assembly, it was decided to design and fabricate a buckle simulator of the required strength. The overall dimensions and geometry were to comply with that required in the end-item specification to

assure system test applicability and provide enough strength to assure dynamic test success.

It was also decided to change the side strap webbing from Type I to Type II per MIL-W-25361 in order to avoid slippage of the webbing through the modified adjusters. The thicker webbing was expected to hold more firmly in the locking device.

DYNAMIC TEST

Purpose

The purpose of the dynamic test was to provide a dynamic evaluation of the restraint system. This test simulated as closely as possible a 95th percentile Army crewmember restrained to a seat in an aircraft crash and thus provided a proof test for the restraint system to be defined by the end-item specification. The dynamic response data obtained were also needed to verify quantitative values for use in the specification.

Restraint System

The restraint system tested was designed to fulfill the overall requirements of the restraint system to be defined by the end-item specification. The test configuration had all of the characteristics and components of the specified restraint system; however, prototype hardware was used where adequate end-item hardware was not available. The restraint system adequately provided for dynamic test evaluation of the specified design. The system is shown prior to testing in Figure 96.

The restraint system consisted of a two-ply lap belt with side straps, a double-strap lap-belt tie-down, and a shoulder harness incorporating the reflected strap approach. Since a single-point release buckle of adequate strength was not available, a plate was designed to simulate a single-point release buckle and fittings. The webbing slots were shaped to match those found in buckle fittings and were located to simulate a typical buckle assembly. This simulator is shown installed in the test restraint system in Figure 97.

The lap belt was anchored to the seat by prototype devices used in the static tests. The side straps were attached to the seat through adjusters also used in the static tests. The double-strap lap-belt tie-down was extended through the seat pan and attached through load cells to a tie-down anchor on the sled floor. This modification to the restraint system was necessary to provide room in the strap lengths for the installation of load cells.

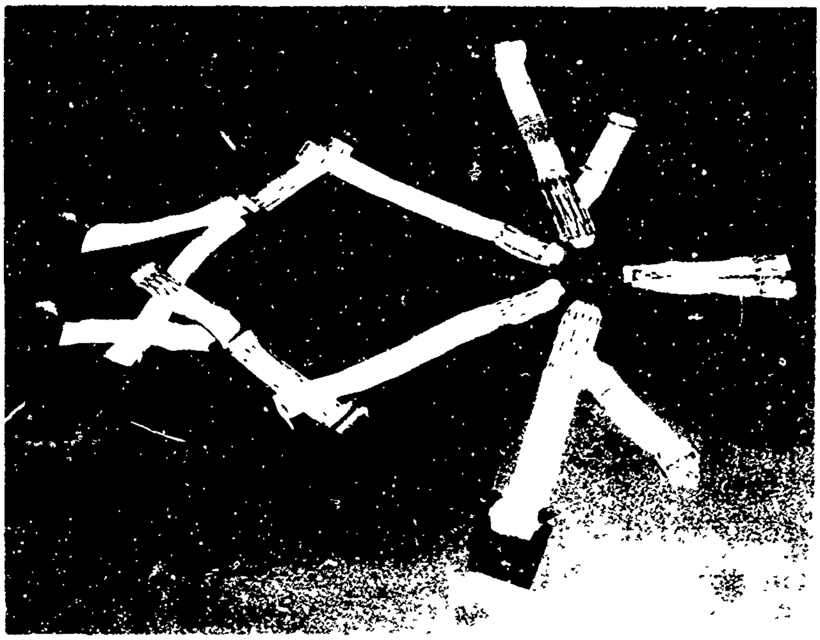


Figure 96. Restraint System Before Test.

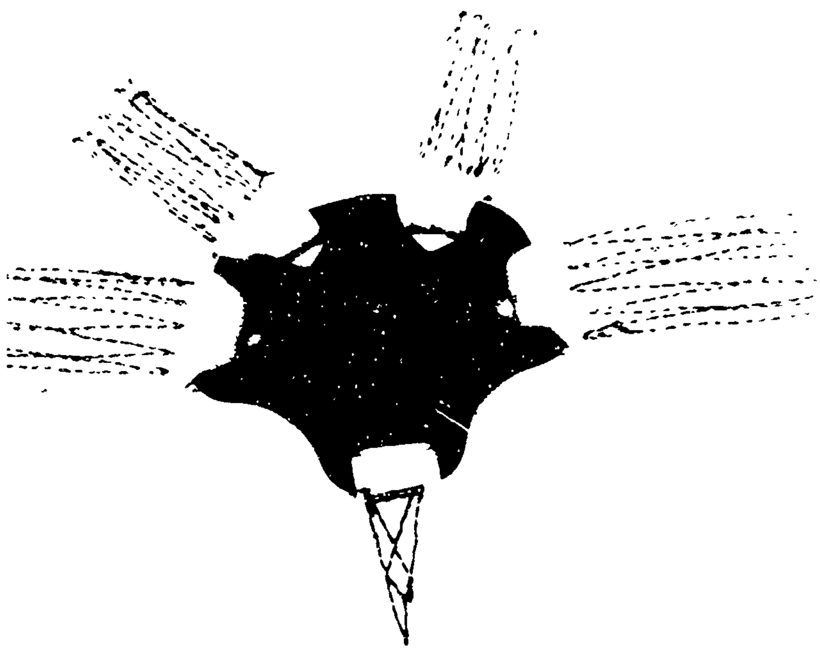


Figure 97. Single-Point Release Simulator.

Seat Occupant

A 95th percentile anthropomorphic dummy equipped with helmet, body armor, and survival kit (vest type) with components, was used as the seat occupant. The dummy was placed in the seat and secured in place with the installed restraint system. Prior to installation in the seat, the dummy joints were torqued to the following values:

	Foot-Pounds
Head attachment joint	20
Shoulder joint (vertical)	80
Shoulder joint (lateral)	40
Elbow	60
Wrist	20
Spinal joint	20
Knee joint	60
Ankle joint	20

The torques were established by trial and error to simulate muscular resistance to movement through joint friction.

The weight breakdown for the dummy and associated equipment is shown below.

	Pounds
Dummy (nude but instrumented)	220.0
Flight suit	2.1
Boots	4.0
Survival kit	3.5
Armored vest	16.2
Helmet	4.3
Restraint system including prototype retractors at 2.5 pounds each and inertia reels at 1.0 pound each	11.0
TOTAL	261.1

Figure 98 shows a rear view of the dummy pelvis and lower spinal regions with the simulated skin and flesh removed. The spinal joint assembly and iliac crest bones of the pelvis

Figure 98. Dummy Pelvis and Lower Spinal Sections.

structure are shown to be visually representative of humans. However, the structural box section connecting the spine to the hip joints does not adequately simulate the buttocks and ischial tuberosities.

The box section below the spinal column normally contains lead ballast for the pelvic region. For this test, it also served as the mount for the three accelerometers located in the pelvic region.

Prior to the test it was decided to dress the occupant in a Nomex flying suit to provide the effect of typical clothing between the restraint system and the dummy flesh. Since dummy flesh is fabricated from an elastomeric material, its coefficient of friction is relatively high. The frictional load between the webbing and the dummy would therefore be larger than normal if placed on the nude dummy. The result would be a

somewhat different response than if clothing were present. The only shortcoming of this test approach is that the clothing tends to mask the movement of certain portions of the dummy.

Seat and Cushion

An existing seat was modified to accept the restraint system. This fixture-type, single-occupant, high-strength (40G) seat weighed approximately 90 pounds.

The seat modification consisted of the addition of a bracket on each side to which the prototype lap-belt retractors were attached. A small platform was also added at the top of the seat back to support the inertia reels.

The seat cushion was made from a 1-inch-thick layer of polyurethane foam (1.6 lb/ft^3 density) on top of 1/4-inch-thick Ensolite (shock-absorbing-type AL foam). The cushion was covered with cotton duck.

Test Environment

The dynamic test environment planned was the most severe survivable combined test required by TR 71-22 for a restraint system. The pulse was primarily longitudinal with a significant lateral component. The seat was mounted at a 30-degree yaw angle to the input velocity vector, as shown in Figure 99. The input pulse for the 95th percentile survivable crash test pulse as defined in Chapter III of TR 71-22 is also shown on this figure. The seat orientation provides for 86.6 percent of the resultant velocity and deceleration vector to be input in a longitudinal direction, and 50 percent to be imposed in a lateral direction relative to the seat occupant.

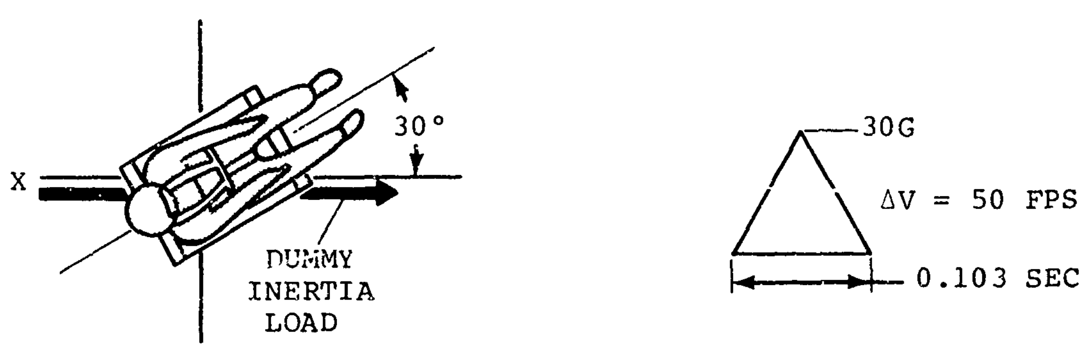


Figure 99. Floor Mount Configuration and Test Pulse Description for the Biaxial Dynamic Test.

The test environment imposes the maximum loading on the restraint system, i.e., all of the inertial load of the dummy is restrained by the restraint system and very little is taken out through the seat as, for example, in a triaxial test. In addition, the equipment which the dummy was wearing provided maximum weight, thus, maximum load for the restraint system to support. The 30-degree yaw provided a large lateral component for proof of the lateral restraint capability of the restraint system.

Instrumentation

Table XXXIV lists the 14 accelerometers and 10 load cells used to record input and response parameters in the test. There were 9 accelerometers used in the dummy, 3 on the seat, and 2 were installed on the sled. The 10 load cells were all used to measure loads in the restraint system components and were located as indicated by the numbers in Figure 100. Black and white still photographs were taken before and after the test to record pertinent information. The high-speed cameras (500 frames/sec) were positioned to record the movement of the occupant and restraint system during impact. A hand-held panning camera was used to record the event in real time.

Calibration

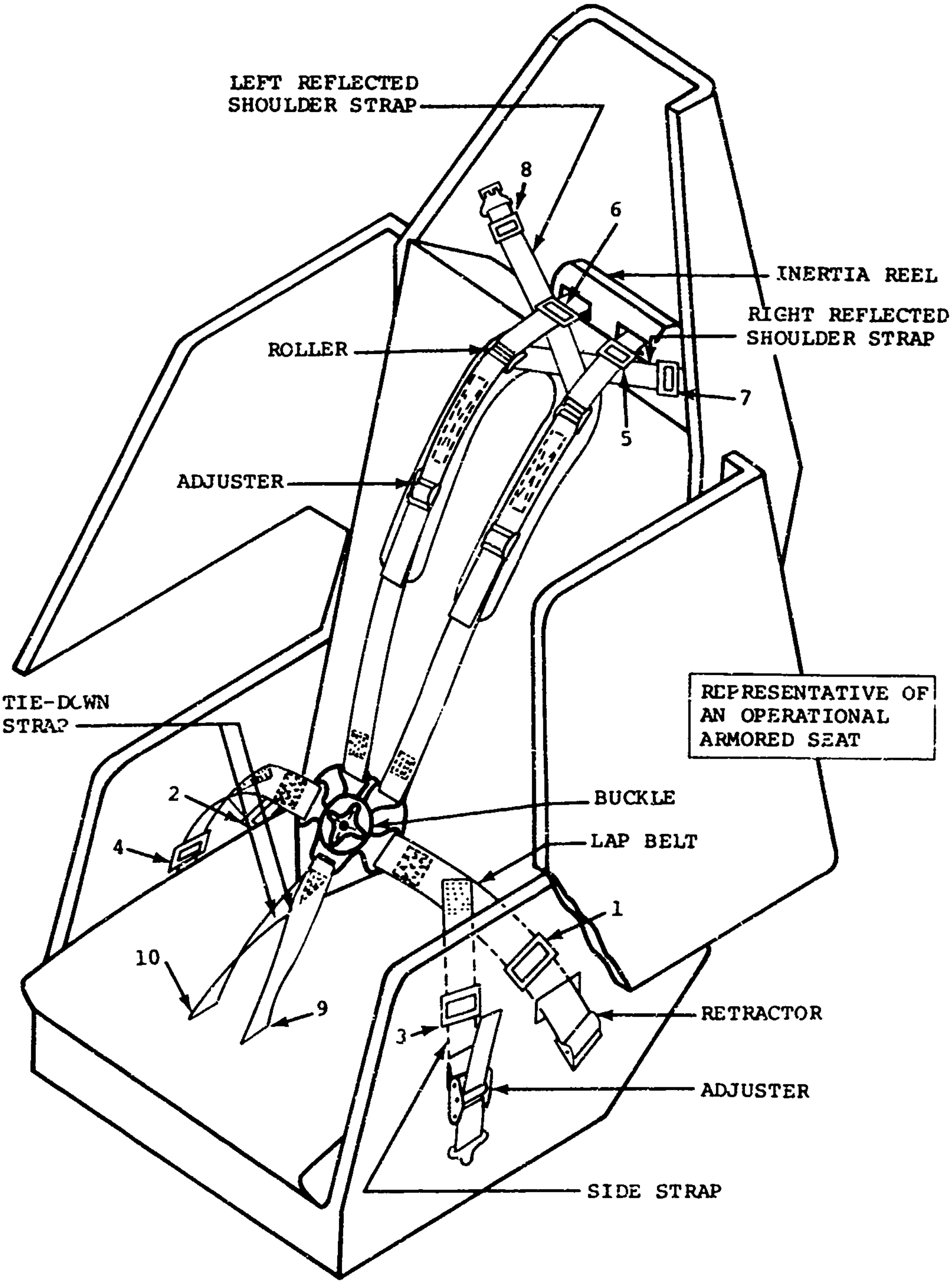
Accelerometers that were current within their calibration period were used. They were tip tested to measure continuity and response at 1G to further assure their operability.

All webbing load cells were calibrated on the tensile tester using a reference load cell traceable to the National Bureau of Standards to measure the load exerted on the cell. The webbing load cells were calibrated using samples of webbing identical to that of the restraint system on which they would be used. The 2 load cells to be used to measure loads in the lapbelt tie-down (not webbing cells) were calibrated in the same fashion as the webbing load cells except that no webbing was necessary. The cells were simply connected between the moving platen of the tensile tester and the reference load cell, and the calibration curve was generated.

Three tests were run to calibrate the sled test device. The desired deceleration test pulse was obtained by using a stack of honeycomb installed in place on the impact face of the barrier. The sled without the test item installed was ballasted to the test configuration weight and impacted into the barrier using the same sled travel distance and weight that was to be used during the dynamic test. Accelerometers were installed on the sled to measure the input acceleration-time pulse.

TABLE XXXIV. INSTRUMENTATION REQUIREMENTS FOR DYNAMIC TEST				
Channel	Type	Capacity	Predicted Peak	Location
1	Load	3500 lb	3000 lb	Lap belt
2	Load	3500 lb	3000 lb	Lap belt
3	Load	3500 lb	1500 lb	Side strap
4	Load	3500 lb	1500 lb	Side strap
5	Load	3500 lb	2500 lb	Shoulder harness
6	Load	3500 lb	2500 lb	Shoulder harness
7	Load	3500 lb	2500 lb	Reflected strap
8	Load	3500 lb	2500 lb	Reflected strap
9	Load	4000 lb	1500 lb	Tie-down strap
10	Load	4000 lb	1500 lb	Tie-down strap
11	Acceleration	100G	30G	X
12	Acceleration	100G	20G	Y Head
13	Acceleration	100G	10G	Z
14	Acceleration	100G	30G	X
15	Acceleration	100G	20G	Y Chest
16	Acceleration	100G	10G	Z
17	Acceleration	100G	30G	X
18	Acceleration	100G	20G	Y Pelvis
19	Acceleration	100G	10G	Z
20	Acceleration	100G	30G	X
21	Acceleration	100G	20G	Y Seat Pan
22	Acceleration	100G	5G	Z
23	Acceleration	100G	30G	Sled*
24	Acceleration	100G	30G	Redundant (Sled)*
*Oriented in a direction parallel to sled velocity vector.				

A tracing of the deceleration-versus-time data measured during the final calibration test is shown in Figure 101. The velocity change was 50.3 ft/sec, slightly above the desired 50 ft/sec, and the peak G was 33, also above the desired 30G.



NOTE: LOAD CELLS 9 AND 10 UNDER SEAT PAN

Figure 100. Load Cell Locations.

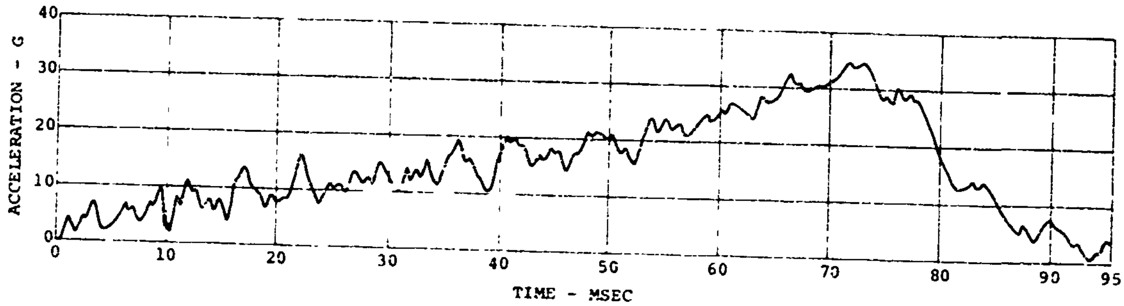


Figure 101. Honeycomb Stack Calibration Trace.

This pulse was accepted as meeting the test requirements within allowable tolerance, and a honeycomb stack identical to the calibration stack was prepared for use in the dynamic test.

Test Procedure

The horizontal accelerator is shown schematically in Figure 102. To conduct a test, the test sled is towed down the track into the crash barrier by a cable attached to a falling weight.

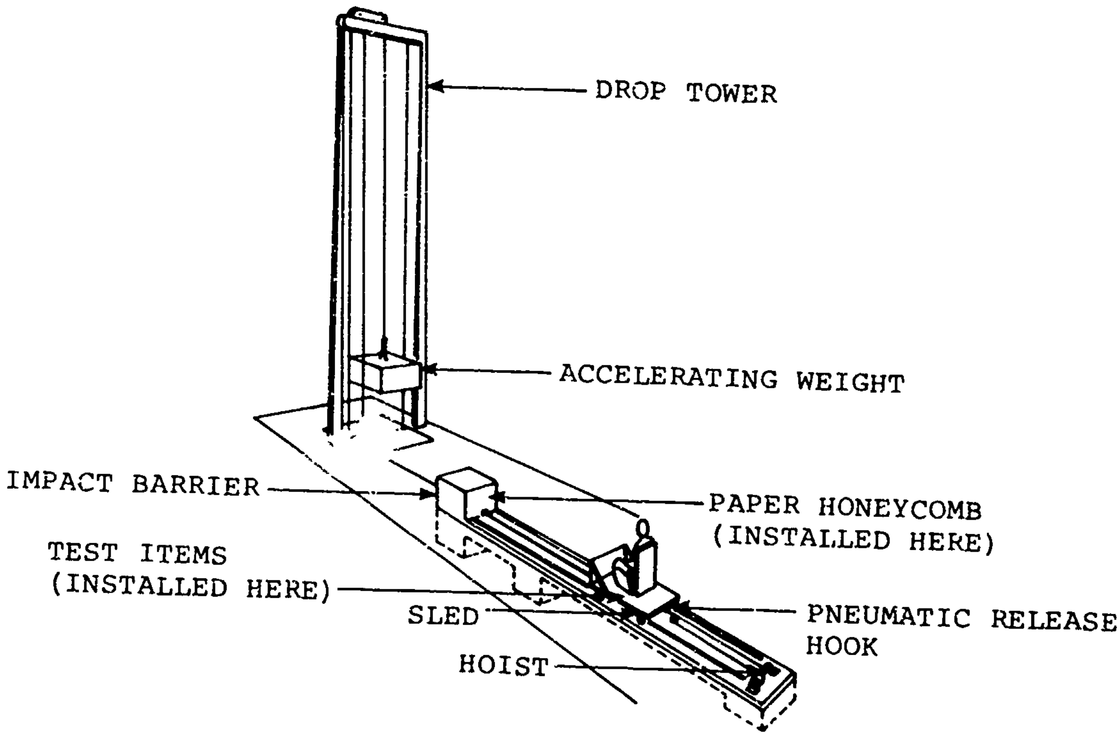


Figure 102. Horizontal Sled Accelerator.

After calibration, the ballast is removed from the sled and is replaced by the test article including seat, restrained occupant, and test fixtures. The test instrumentation is then connected and pretest electrical calibration is conducted.

Figure 103 is a pretest view of the test assembly that also shows the crash barrier and the honeycomb stack mounted on its face. The grid board visible on the back side of the sled is used to provide a reference for analyzing the dynamic response of the test item.

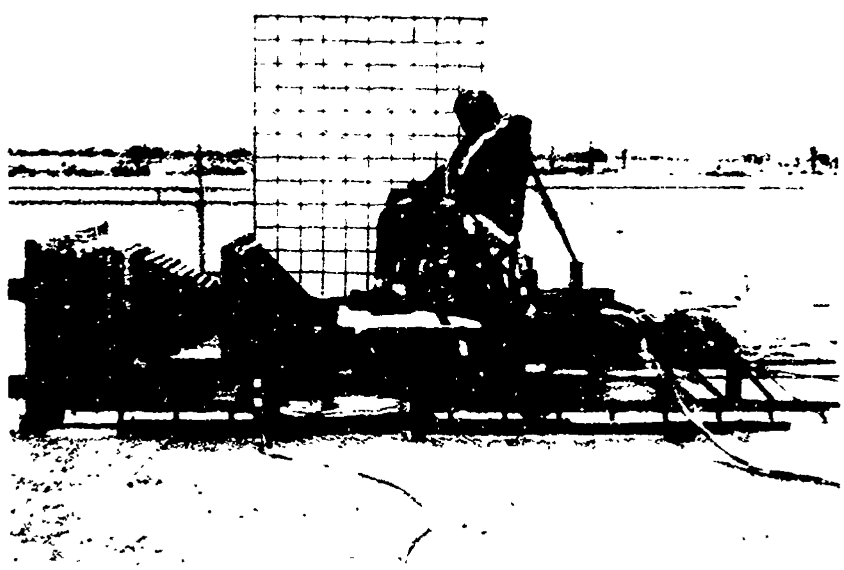


Figure 103. Pretest View of Test Assembly.

Figure 104 presents a lateral view of the test item (dummy and seat). Figure 105 presents a frontal view of the test item and Figure 106 is a view of the test assembly from a direction nearly coincident with the longitudinal axis of the track. This photograph was taken from standing height atop the crash barrier looking down the longitudinal axis of the track.

The umbilical cord which transmits the transducer data from the test assembly to the recording system is visible in most of the figures. The sled release hook is visible on the rear end of the sled, and in Figure 105, the impact switch on the

Figure 104. Pretest Lateral View of Test Item.

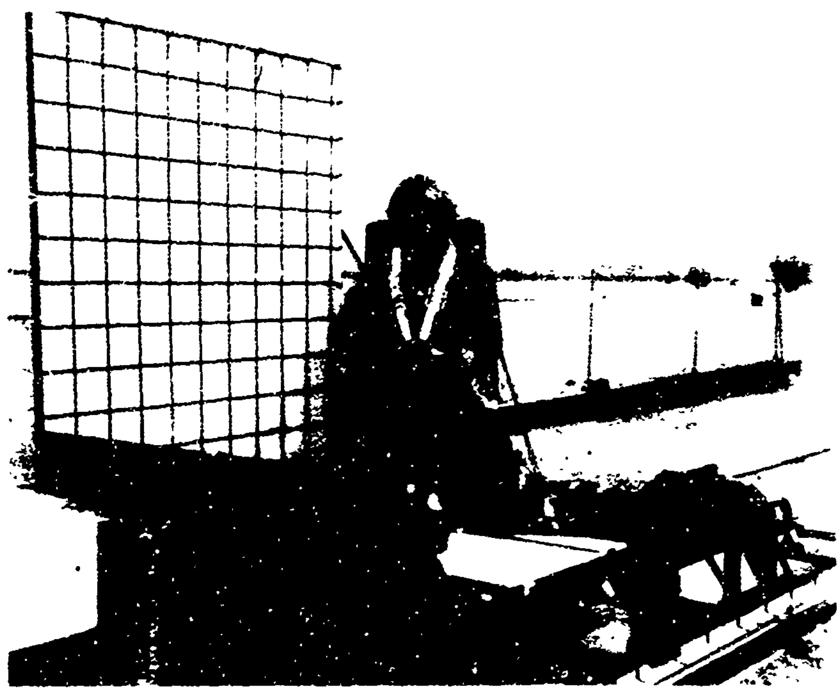


Figure 105. Pretest Frontal View of Test Item.

Figure 106. Pretest Frontal View of Test Assembly.

front of the sled impact face is visible. This contact switch is closed when the sled impacts the tip of the honeycomb stack, thus providing an impact time from which to reference test events.

Test Results

General

Figure 107 is a lateral view of the sled, barrier, and test assembly taken after the test. The crushed honeycomb stack can be seen on the face of the barrier, and the sled and dummy are shown in their final rest positions.

The restraint system restrained the dummy in the seat throughout the pulse. There were no subsystem failures and, in spite of the bulky survival vest and armored vest,

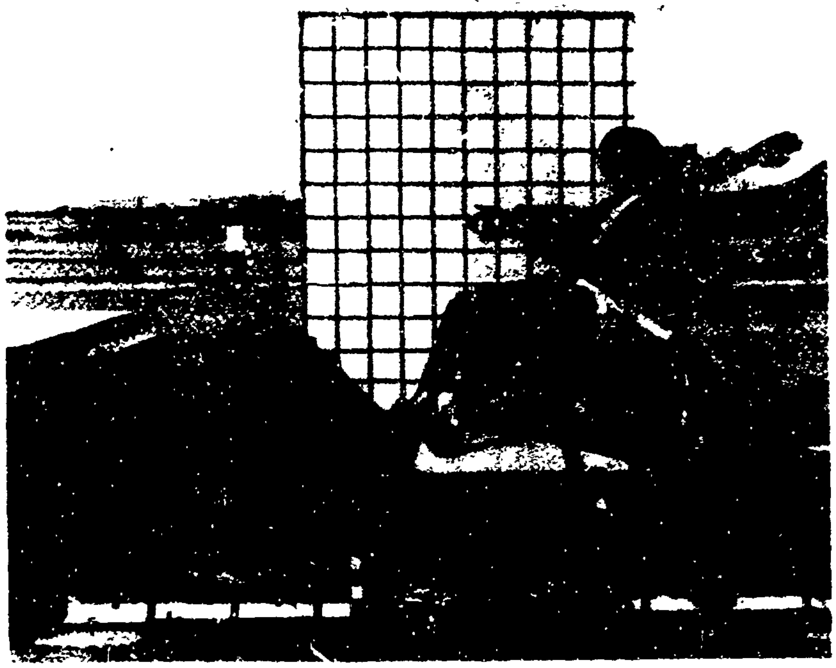


Figure 107. Posttest Lateral View of Test Assembly.

the restraint system performed its function. Lateral restraint was exceptionally good, with very little lateral dynamic movement and essentially no permanent lateral movement noted. There was considerable permanent longitudinal pelvis movement, but no submarining was evident.

Figure 108 is a posttest lateral view of the test item. Figure 109 is a posttest view of the test article taken from a direction approximately coincidental with the longitudinal axis of the dummy and the seat. Figure 110 is a posttest view of the test assembly taken from standing height atop the barrier and coindicental with the longitudinal access of the sled track. This group of figures documents the final position and condition of the dummy and the restraint harness. Although the dummy shifted forward in the seat, all components were in place and the lap belt did not ride up over the iliac crest bones during the test pulse.

Posttest views of the restraint system are shown in Figures 111 and 112. Figure 111 shows the system from the side and Figure 112 shows the system from the front bottom-end position. All components were intact and in good condition.

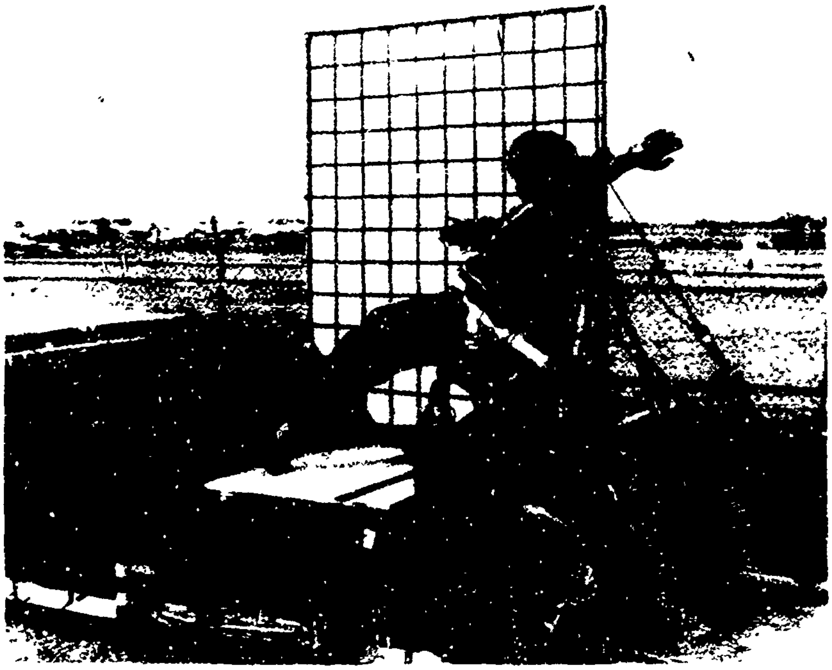


Figure 108. Posttest Lateral View of Test Item.

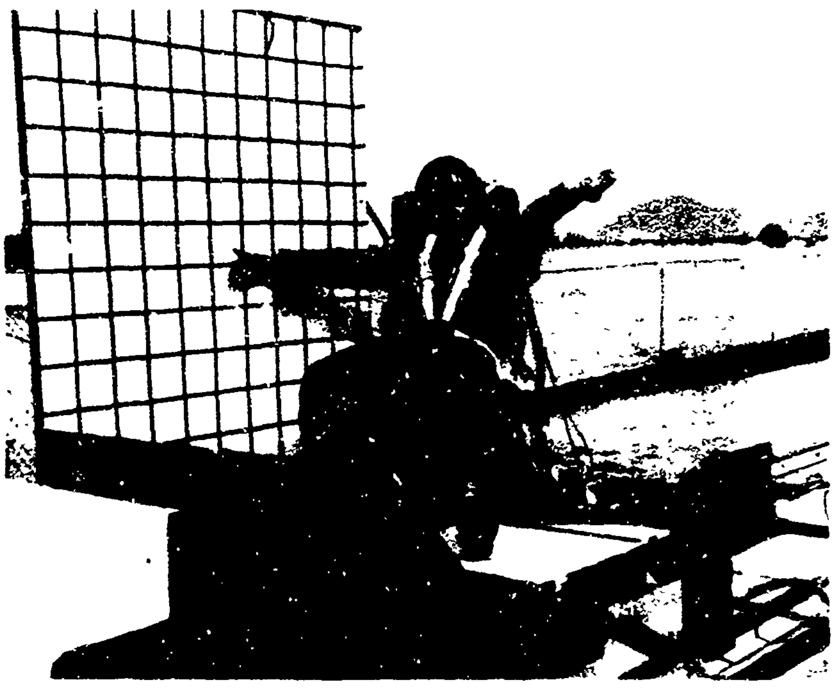


Figure 109. Posttest Frontal View of Test Item.

Figure 110. Posttest Frontal View of Test Assembly.

Figure 111. Posttest Side View of Restraint System.

Figure 112. Posttest Frontal-End View of Restraint System.

Deceleration Data

Measured deceleration-versus-time traces are presented in Appendix I. These data were integrated for velocity change and analyzed. Also, peak decelerations were determined from the traces and overshoot factors were calculated. These data are summarized in Table XXXV.

The resultant velocity change of the sled and its peak deceleration are shown in the table. The input velocity change was 54 ft/sec. This exceeds the 95th percentile survivable crash pulse velocity change which has been established at 50 ft/sec. However, the peak deceleration of the sled reached only 24.4G rather than the desired 30G. Since the velocity change determines the energy input to the system, it is apparent that the energy content of the achieved test pulse exceeded the 95th percentile survivable crash pulse.

The desired peak deceleration of the sled was not achieved during the dynamic test; this occurred in spite of using the identical honeycomb stack design and impact velocity determined to be acceptable in the final calibration test. The calibration pulse was shown in Figure 101.

TABLE XXXV. SUMMARY OF DECELERATION DATA				
Location	Axis	Velocity Change (ΔV, ft/sec)	Peak Deceleration (G)	Overshoot
Head	Longitudinal X	25.8	33.8	1.6
Head	Lateral Y	23.5	18.3	1.5
Head	Vertical Z	50.3	32.3	
Chest	Longitudinal X	37.0*	40.5*	1.92*
Chest	Lateral Y	26.8	27.9	2.29
Chest	Vertical Z	No Data		
Pelvis	Longitudinal X	36.4*	26.2*	1.24*
Pelvis	Lateral Y	26.4	26.4	2.16
Pelvis	Vertical Z	29.9	32.4	
Seat Pan	Longitudinal X	42.5	21.6	
Seat Pan	Lateral Y	25.7	13.3	
Seat Pan	Vertical Z	0	0	
Sled	Resultant	54	24.4	
Sled in Seat Longitudinal Direction		46.8	21.1	
Sled in Seat Lateral Direction		27	12.2	

*These data were estimated from suspect traces. Explanation is made in Discussion of Results.

It can be seen that the peak deceleration measured on the calibration pulse was 33G. The integrated velocity change under the curve was 50.3 ft/sec. In an effort to explain why the test results did not match the calibration results, the honeycomb stack used for the calibration pulse and the stack used in the dynamic test pulse were inspected. Figure 113, a side view of the compressed calibration stack, shows that all of the layers are crushed down to the bottom backup layer. The force exerted to decelerate the sled was progressively increased by crushing of the smaller layer areas, followed by crushing of the next larger layer, etc., thus providing the increase in force and increase in deceleration desired.

Figure 113. Side View of Calibration Honeycomb Stack.

Figure 114 is a front edge view of the test stack. It is apparent that local crushing of the second layer from the bottom occurred toward the center under the uncrushed third layer. The third layer of honeycomb was to provide the maximum force decelerating the sled, and thus provide the maximum deceleration level. This layer was not crushed and the energy was absorbed through local crushing of the underlying layer and compression of air. The maximum force and the maximum deceleration required were therefore not achieved.

Figure 115 shows a rear edge view of the test stack. It is apparent that consistent crushing across the stack was not achieved either, and that there was a distinct discontinuity in the lower layers of the stack.

It is believed that individual differences in the airtightness of the honeycomb sheets are responsible for the malperformance of the test stack. This problem has been evidenced in long, rectangular shaped stacks in which there was more trapped air, but it has not been encountered in the past with honeycomb stack configurations similar to the one used in this test.

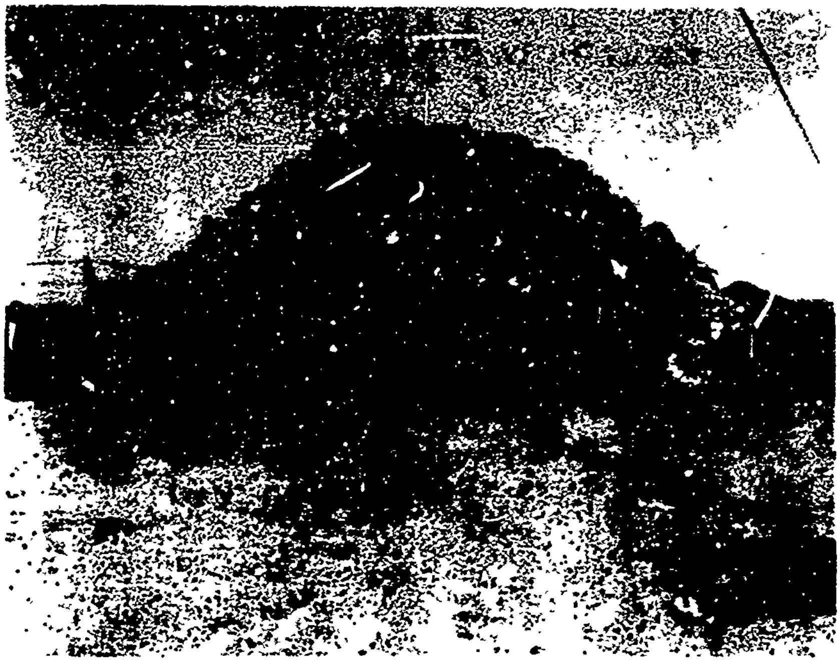


Figure 114. Front Edge View of Test Honeycomb Stack.

Figure 115. Rear Edge View of Test Honeycomb Stack.

For reference purposes, the longitudinal and lateral input components relative to the seat axes were computed and are shown at the bottom of Table XXXV. The velocity components coinciding with the longitudinal and lateral axes were 46.8 ft/sec and 27 ft/sec, respectively. Peak deceleration calculated for these same directions indicates that the input deceleration reached 21.1G in the longitudinal direction and 12.2G in the lateral direction relative to the seat.

The velocity change along the longitudinal axis of the seat pan was 42.5 ft/sec and along the lateral axis was 25.7 ft/sec. Also, the peak deceleration along the longitudinal axis of the seat pan was 21.6G and along the lateral axis was 13.3G. The seat pan input to the dummy and restraint harness is very similar to that input to the seat by the sled.

No vertical deceleration data were obtained in the chest of the dummy; however, the vertical deceleration of the pelvis exceeded that of the other two axes. The vertical deceleration was 32.4G compared to 26.4G in the lateral direction and an estimated 26.2G in the longitudinal direction.

Although the longitudinal deceleration of the head exceeded the lateral and vertical, the vertical deceleration very closely approached the magnitude of the longitudinal. The longitudinal deceleration of the head was 33.8G, the lateral deceleration was 18.3G, and the vertical deceleration was 32.3G.

The maximum longitudinal deceleration estimated for the chest was in the neighborhood of 40G, whereas the measured lateral deceleration was 27.9G.

Overshoot factors computed on the basis of the seat pan input ranged from 1.5 to 2.2G (see Table XXXV).

Load Data

The individual load-versus-time traces measured during the test are included in Appendix I. Peak load values for the various components were determined from the traces and are presented in Table XXXVI.

TABLE XXXVI. SUMMARY OF LOAD DATA	
Location	Peak Load (lb)
Lap Belt Left	2695
Lap Belt Right	2400
Side Strap Left	540
Side Strap Right	780
Shoulder Harness Left	446
Shoulder Harness Right	1450
Reflected Strap Left	282
Reflected Strap Right	1620
Tie-Down Strap Left	50
Tie-Down Strap Right	0

Displacement Data

High-speed film analysis provided the longitudinal displacement of various items as shown in Table XXXVII. Velocity change was also computed to be 52 ft/sec from the film data, which correlates rather well with the integrated deceleration value of 54 ft/sec.

TABLE XXXVII. LONGITUDINAL DISPLACEMENT DATA		
	Maximum Movement (in.)	
Location	Relative to Sled	Relative to Seat
Head	13.9	10.4
Right Shoulder	12.4	8.9
Buckle Simulator	6.9	4.2
Top of Seat Back	3.6	-
Retractor	2.7	-

Discussion of Dynamic Test Data

A matter of primary concern appeared to be the relatively large longitudinal displacement of the dummy pelvis. It appeared that submarining had somehow occurred in spite of the use of the side straps and the buckle tie-down strap. Closer observation of the film data, however, showed that the relatively large longitudinal movement of the pelvis was due to two items: the lap-belt angle and the buckle simulator placement on the dummy.

First, proper location of the lap-belt tie-down (2-1/2 inches forward of the seat reference point) provided a 45- to 55-degree angle between a horizontal plane through the seat reference point and the laterally projected center line of the lap belt. This resulted in essentially the same vertical load component as longitudinal in the lap belt. Consequently, the forward placement of the lap-belt tie-down produced a higher load in the lap belt to sustain the longitudinal deceleration force of the dummy. This permitted more elongation which increased net longitudinal movement.

The high vertical loading allows more belt rotation about its attachment point, and thus permits additional longitudinal movement of the dummy. These allowances were planned to assure that the lap belt would not ride up and over the iliac crest bones of the pelvis and result in submarining.

Secondly, the addition of the buckle simulator provided a rather large, relatively rigid surface for bearing load against the dummy. The posttest photographs show that the top edge of the simulator plate rode up over the lower edge of the rigid armored vest. This location thus permitted the pelvis to rotate under the forward edge of the armored vest to some extent before the webbing tightened around the iliac crest of the pelvis. This also added to the forward movement of the pelvis.

Another general consideration is that the webbing of the harness was not tightened excessively prior to test. Only the slack was taken out of the webbing components which is more realistic of the end-item restraint system use; this varies somewhat from typical test practice when restraint components are tightened unrealistically prior to testing.

Although the dummy used in this test was relatively sophisticated and provided very good simulation of portions of the human subject, an unexplainable characteristic has been noted in the two test programs conducted with this dummy. The testing conducted in support of the development of a crashworthy

integrally armored crew seat (Contract DAAJ02-69-C-0030) also produced extremely high vertical decelerations for pulses in which there was no input vertical component. It is believed that the box-shaped structure underneath the pelvic bone structure to simulate an occupant buttocks may be the cause. The box structure does not have the ischial tuberosities, and thus has more flesh simulation and an unreal underlying bony structure. For example, on the previous seat tests, the corner of the box structure actually cut through the cushion and impacted the seat bottom during one of the tests. It is believed that this characteristic of the dummy provides unreal vertical deceleration and that these data should be ignored in the longitudinal and lateral evaluation of dynamic test response. Dummy simulation of human response is known to be rather unrealistic and unrepeatable. However, dummy use constitutes a vehicle for providing test confirmation of human restraint performance and therefore provides the most accurate simulation available.

Consideration must be given to the design of protective devices within the occupant strike zone in the aircraft compartment, as emphasized by the flailing of the dummy arms and legs during the test. All components which the legs, arms, or head could strike should be designed for this impact and should be padded and configured to minimize the injury. Since this harness has been specifically designed to improve lateral restraint, the strike zone will be lessened. Consequently, limb and head injuries so prevalent in rotary-wing aircraft accidents at this time should be reduced by the use of this restraint system.

The use of the vest-type survival kit and the ballistic armor vest may have also added to the longitudinal movement. Webbing located over components inside of pockets on the front of the vest would depress and crush under the loading and thus allow some forward dummy movement.

Data acquisition problems were encountered with three accelerometers located as follows: longitudinal axis in the chest, longitudinal axis in the pelvis, and vertical axis in the chest. Data were recorded on the two longitudinal accelerometers, but none were obtained from the vertical accelerometer.

Observation of the data measured by the faulty longitudinal accelerometers showed that the traces had zero shifts and other unexplainable features. However, since the test pulse was recorded, an attempt was made to establish a zero line and to obtain whatever data might be available from the trace. These data should be used as reference only, since they are suspect. The data are presented in Appendix I. Handling of the data is explained in the following text.

To estimate the zero line for the longitudinal data traces, it was assumed that the resultant pelvic velocity change in the longitudinal (ΔV_x), lateral (ΔV_y), and vertical (ΔV_z) directions should be equal to the input velocity change (ΔV). That is,

$$\Delta V = \sqrt{(\Delta V_x)^2 + (\Delta V_y)^2 + (\Delta V_z)^2}$$

Substituting the known values for $\Delta V = 54$ ft/sec, $\Delta V_y = 26.4$ ft/sec, and $\Delta V_z = 29.9$ ft/sec, and then solving for ΔV_x produced

$$\Delta V_x = \sqrt{(54)^2 - (26.4)^2 - (29.9)^2}$$

$$= \sqrt{1325} = 36.4 \text{ ft/sec}$$

The zero line was shifted until the area under the curve integrated with the planimeter equaled 36.4 ft/sec. The resulting data trace was then treated as an estimate of the measured data.

Since data in the chest vertical direction were not obtained, the vertical velocity change for the chest was assumed to be identical to that of the pelvis. The same approach used for the pelvis was then used for the chest.

The seat and its tie-down devices were expected to be extremely rigid based on reports from previous test programs using this fixture-type seat. Subsequent detailed analysis of the film data, however, showed that significant seat pan forward movement occurred during the test which tended to produce slack in the lap-belt tie-down webbing because of its angle relative to the motion of the seat.

Because of this slack, the tie-down function was performed almost totally by the side straps connected to the center of the lap belt. This is apparent in the loading recorded in these harness members. The load measured on the left-center tie-down strap was due to lateral thigh loading of the left leg and was not significant, reaching only 50 pounds. In the eventual seat system where the center tie-down strap is attached to the seat pan and thus moves with the seat, it is expected that the tie-down straps will carry more of the shoulder harness load, leaving the side straps to perform their basic lateral restraint function for the thighs.

Overall, the restraint harness performed exceptionally well, restraining the occupant in the longitudinal direction without

submarining and providing exceptionally good lateral restraint. It can be expected that, without the encumbrances of the survival kit and the armored vest, the restraint system would perform even better. Consequently, it is believed that the features of this restraint system, when incorporated, will provide a distinct improvement in aircrew restraint.

Conclusions

The following conclusions were arrived at based on the dynamic test:

1. The restraint system performed its design function satisfactorily, keeping the decelerative loads imposed on the occupant to a minimum.

2. The restraint system provides exceptionally good lateral restraint of both the upper torso and the thighs.

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APPENDIX I

MEASURED DECELERATION AND LOAD VERSUS TIME DATA (DYNAMIC TEST)

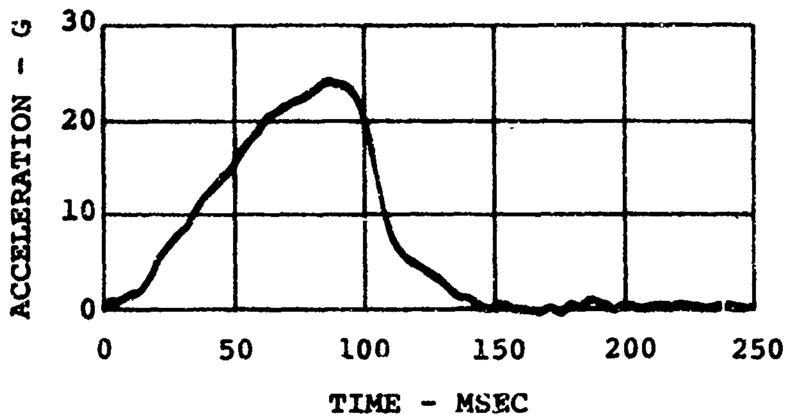

Figure 116. Input Deceleration Pulse.

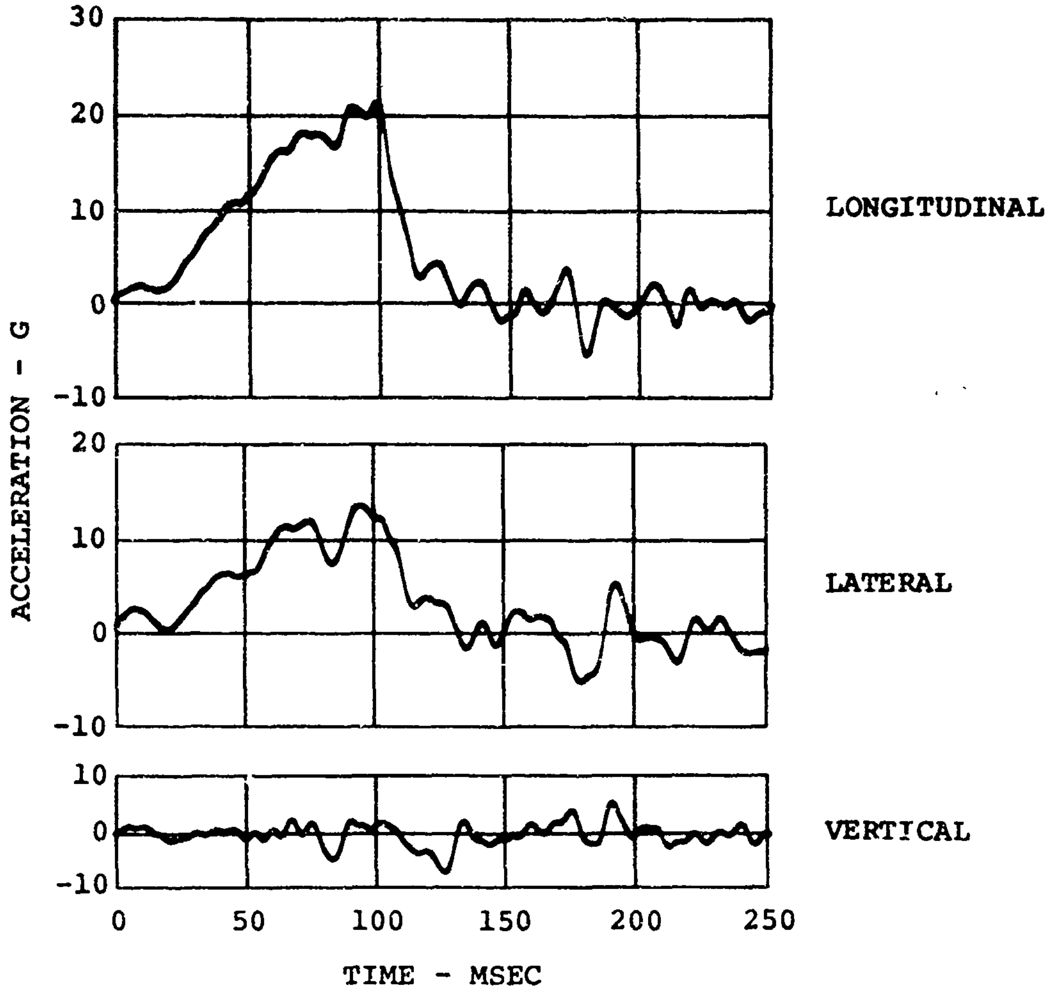

Figure 117. Seat Pan Response.

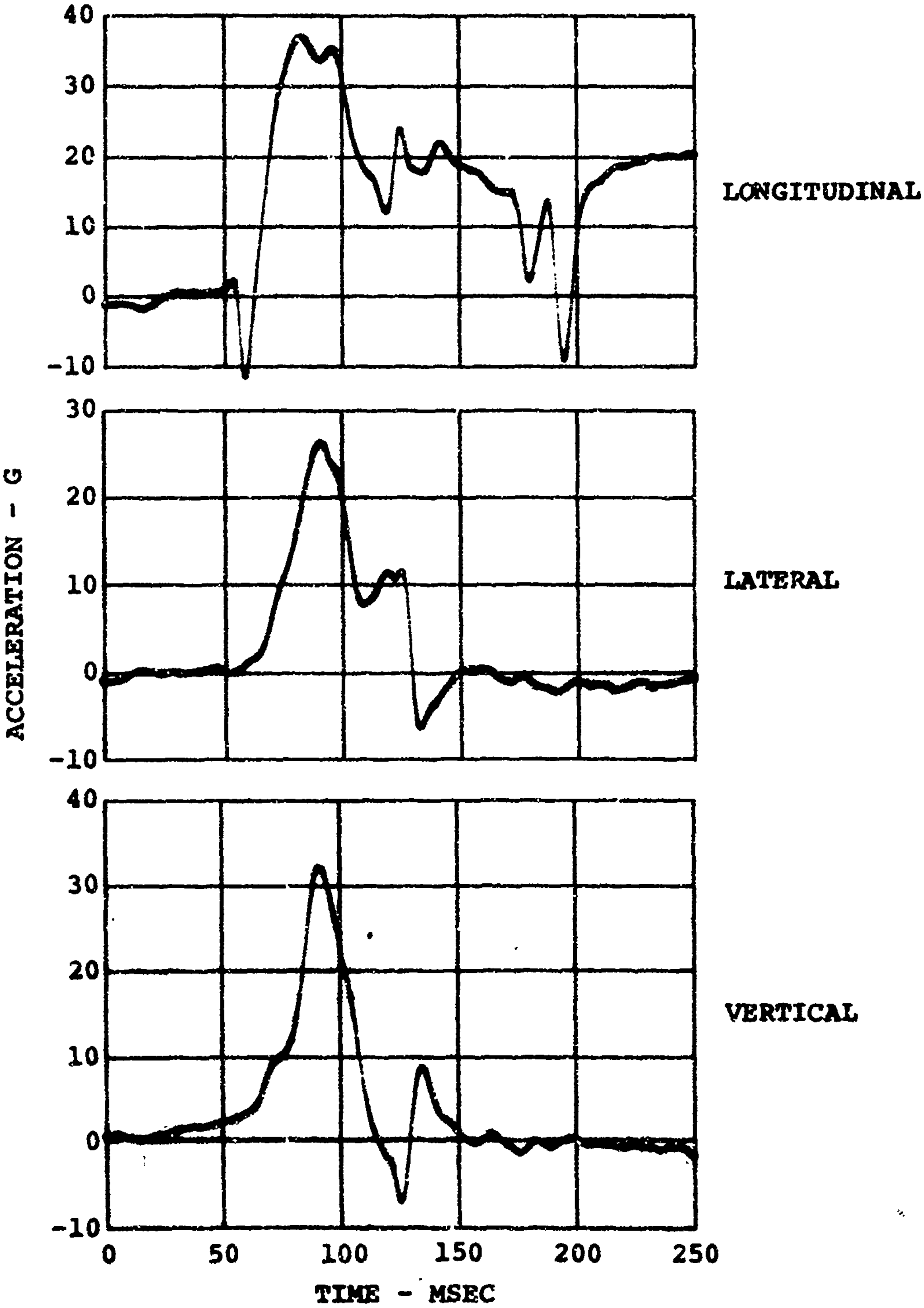

Figure 118. Pelvic Response.

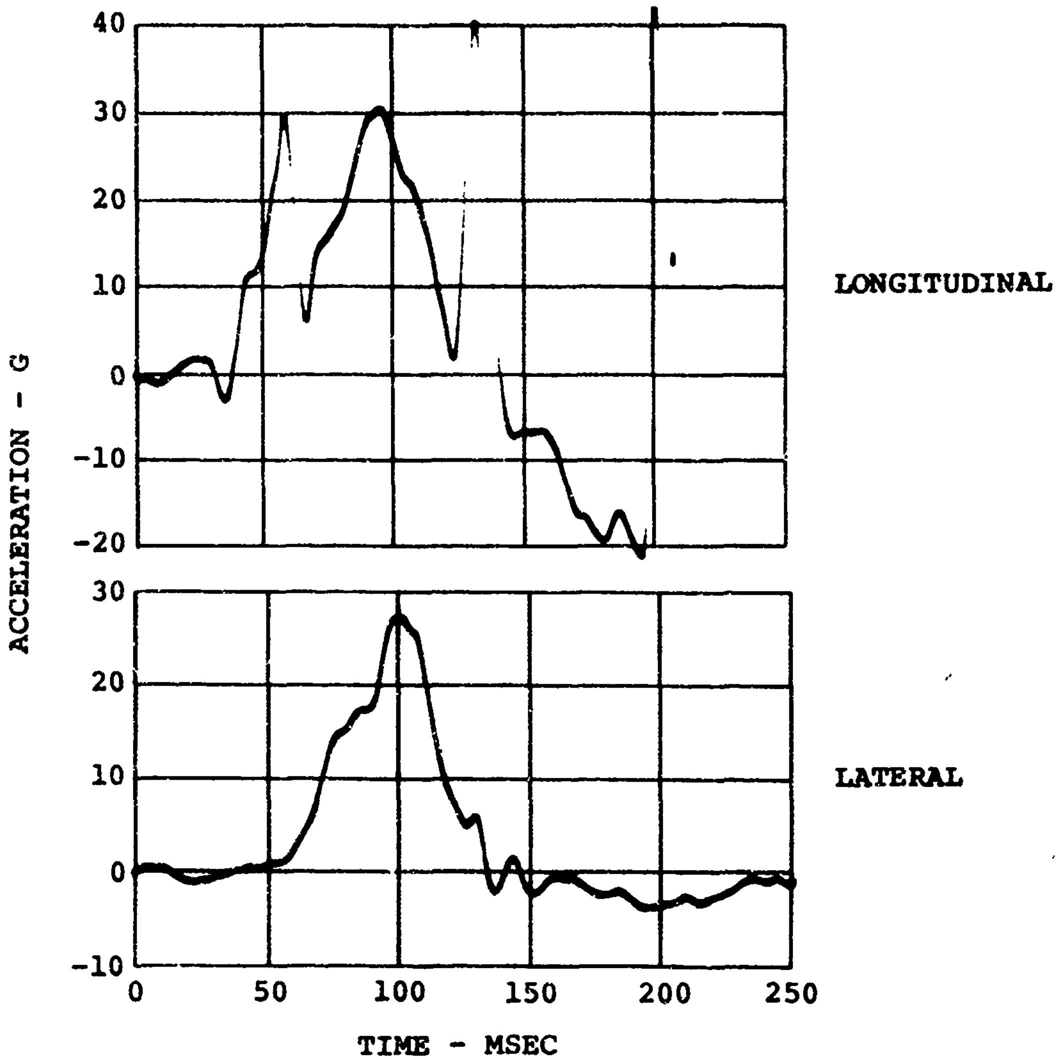

Figure 119. Chest Response.

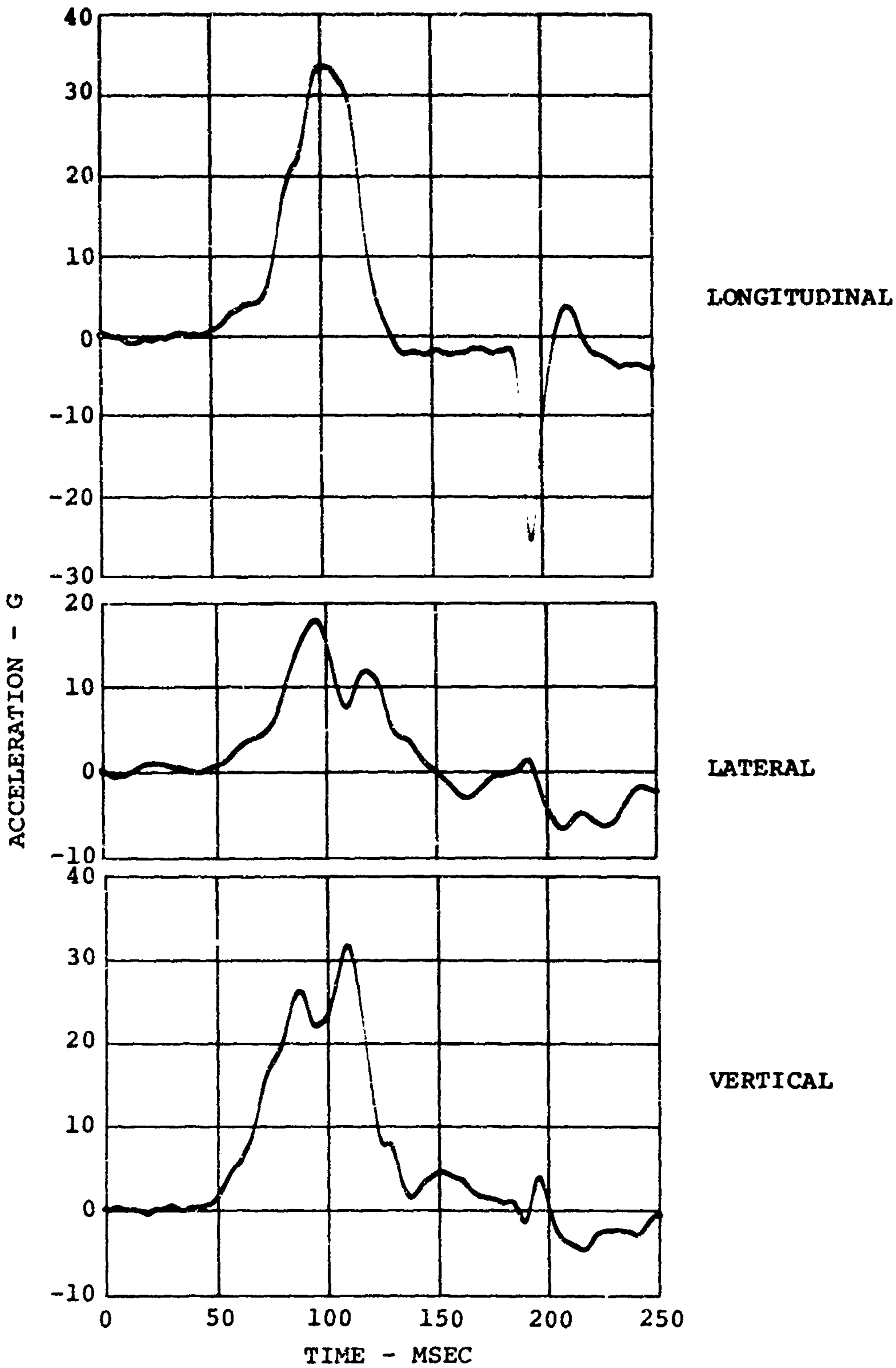

Figure 120. Head Response.

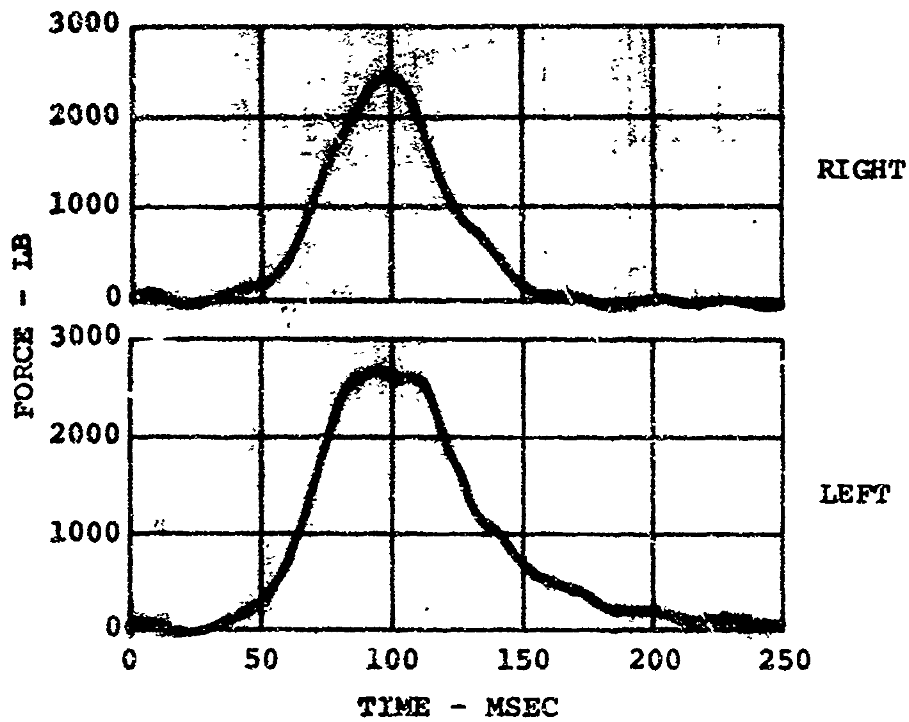

Figure 121. Lap-Belt Loads.

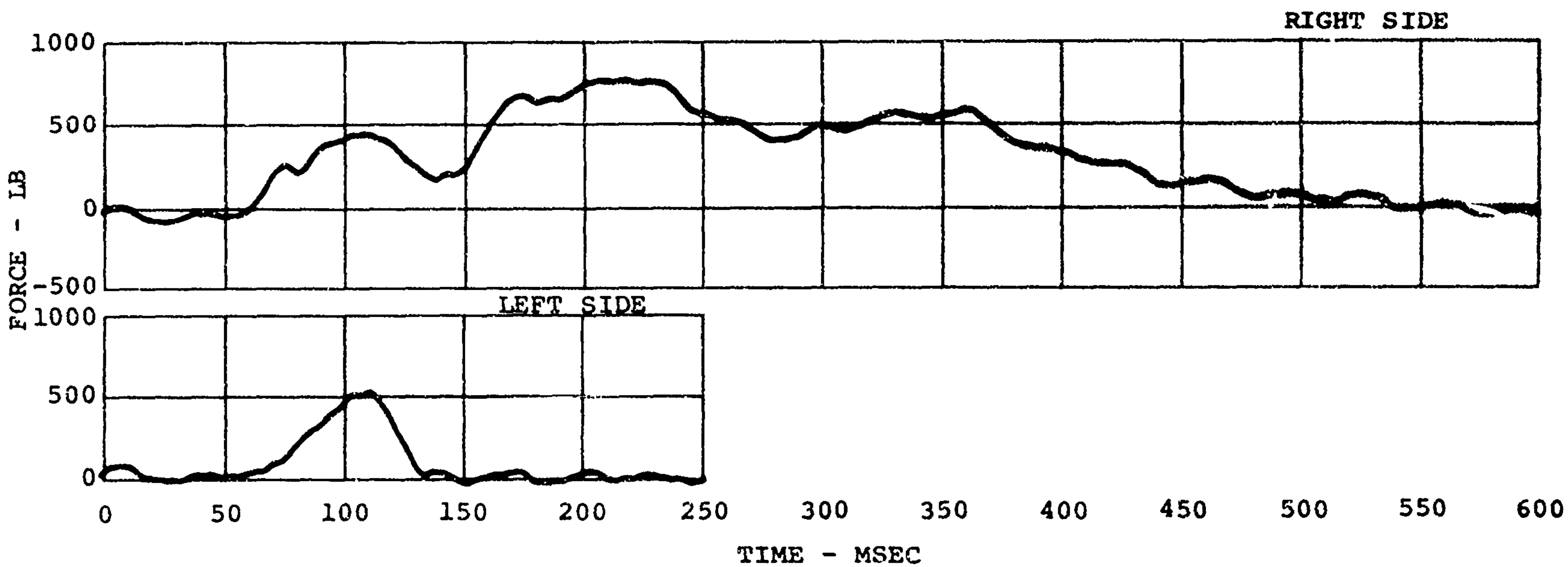

Figure 122. Lap-Belt Side Strap Loads.

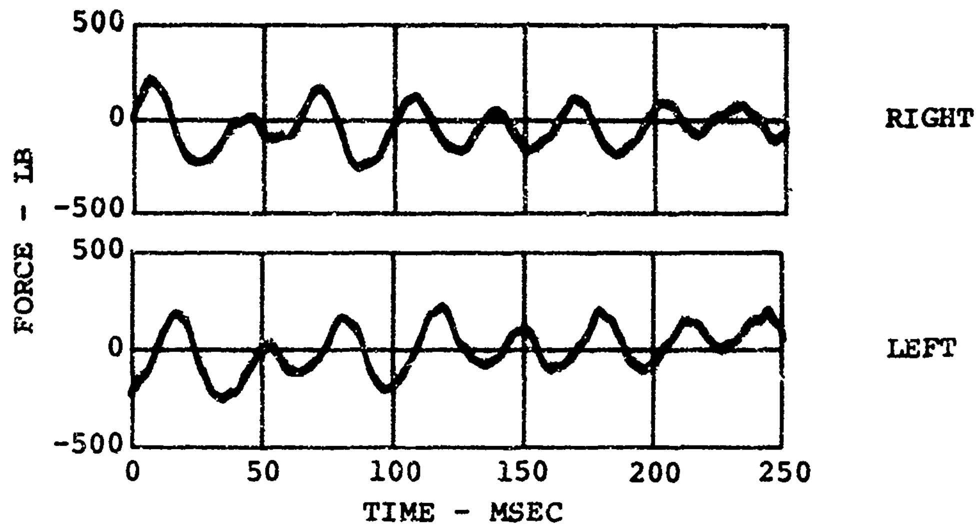

Figure 123. Tie-Down Strap Loads.

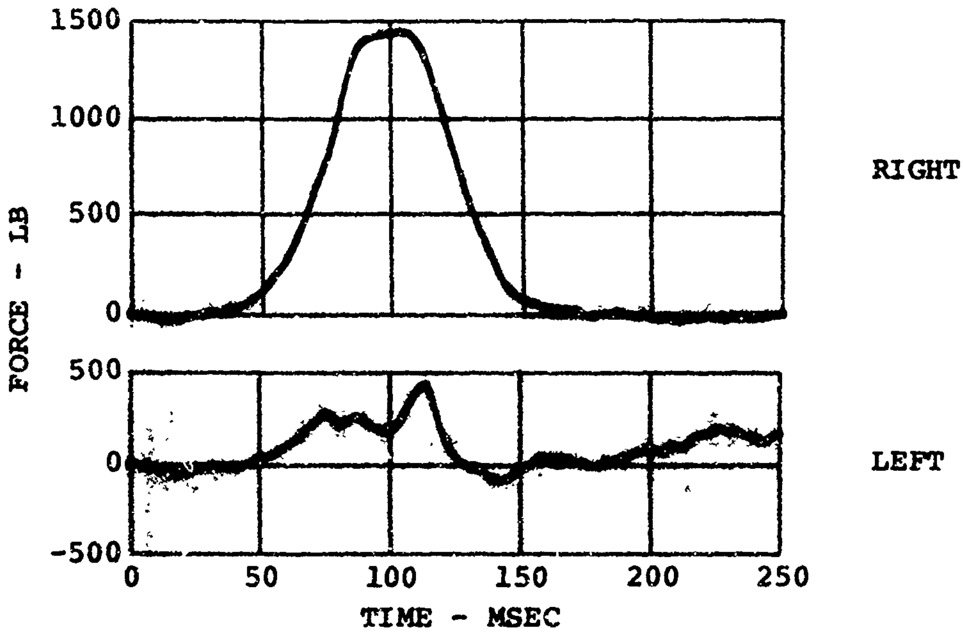

Figure 124. Lower Shoulder-Harness Strap Loads.

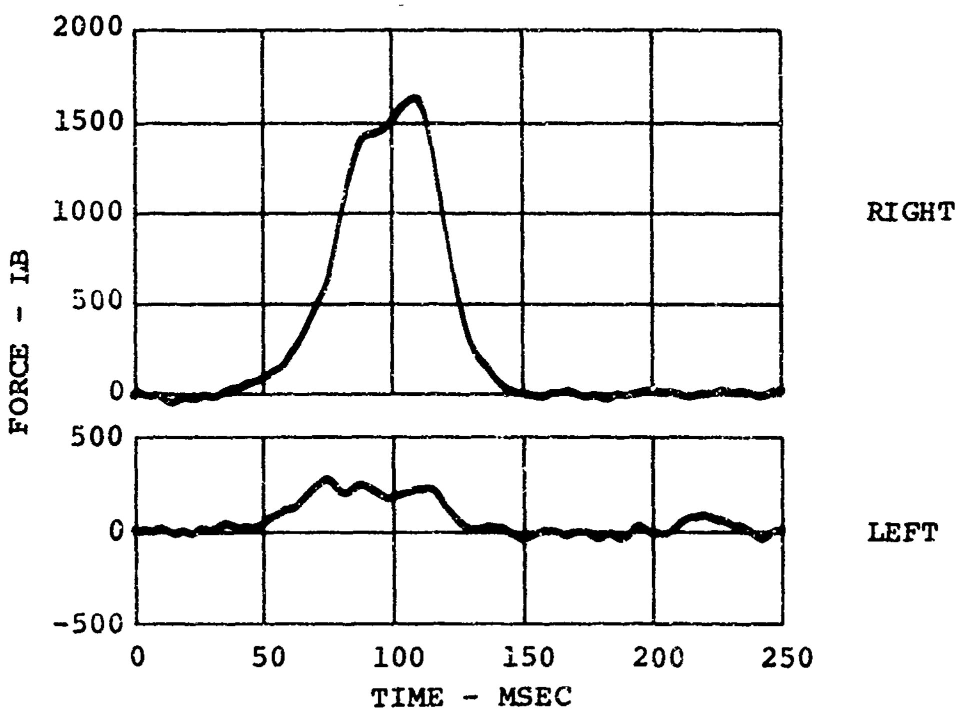

Figure 125. Reflected Strap Loads.

APPENDIX II

STATIC LOAD-ELONGATION DATA FOR VARIOUS WEBBINGS

This appendix contains additional static load-elongation data for various webbings. Although the data were measured in 1966, they are still applicable for comparable webbing types. The data were measured by Brown Line, Inc., and provided to Dynamic Science in the form presented for use in restraint system analyses.

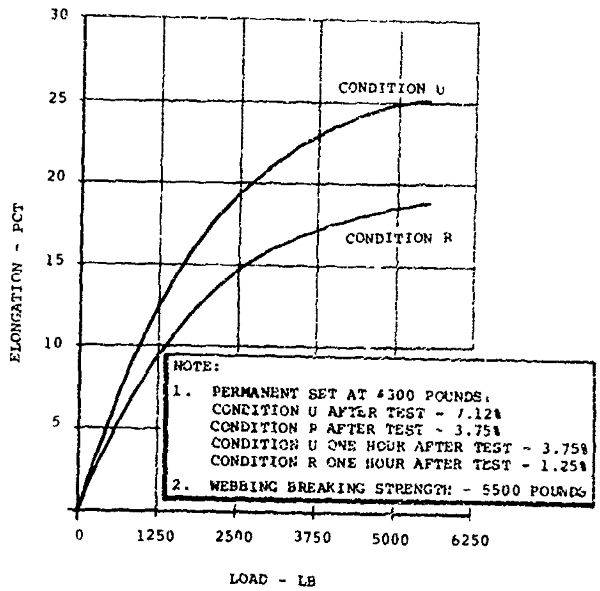

Figure 126. Elongation Versus Load for Type VII Nylon Webbing Condition R per MIL-W-27265 and Condition U per MIL-W-4088.

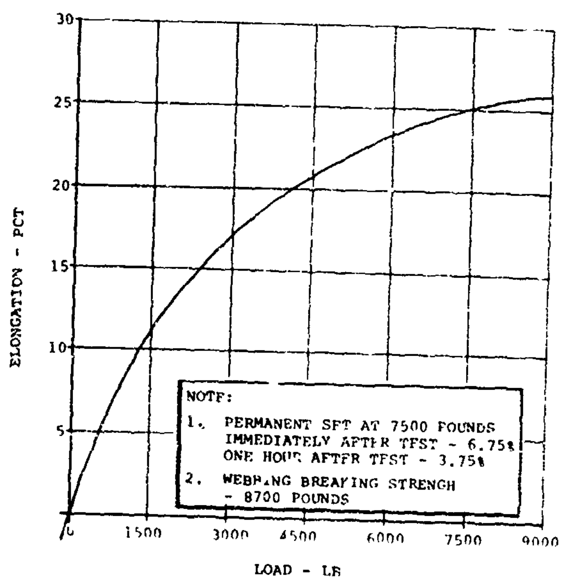

Figure 127. Elongation Versus Load for Type X Condition R Nylon Webbing per MIL-W-27265.

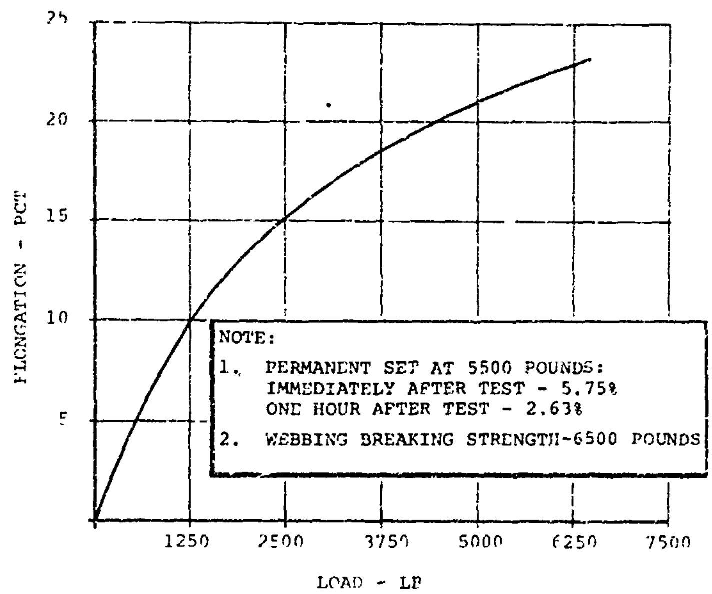

Figure 128. Elongation Versus Load for Type XIII Condition P Nylon Webbing per MIL-W-27265.

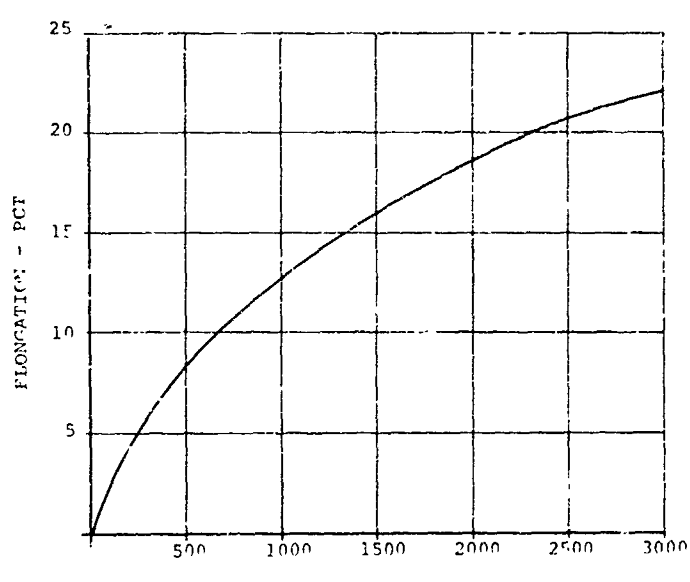

Figure 129. Elongation Versus Load for Type XVII Natural Nylon Webbing per MIL-W-4088.

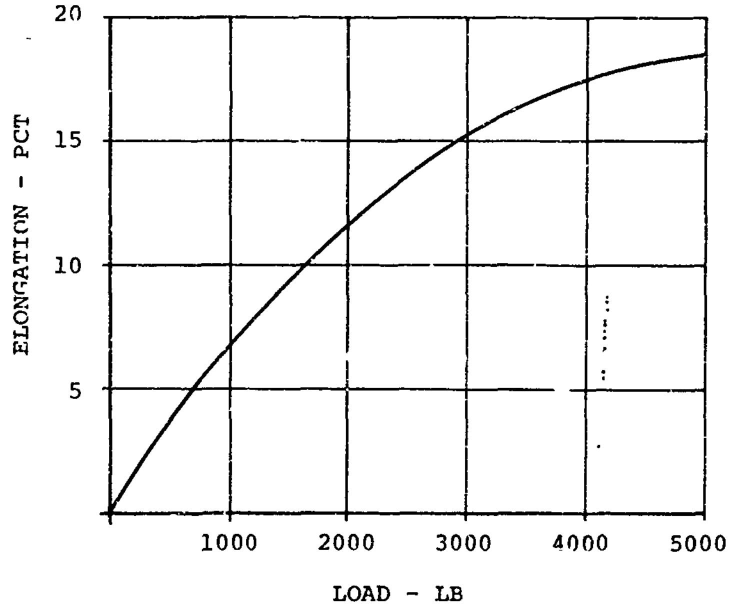

Figure 130. Elongation Versus Load for Type XVIII Natural Nylon Webbing per MIL-W-4088.

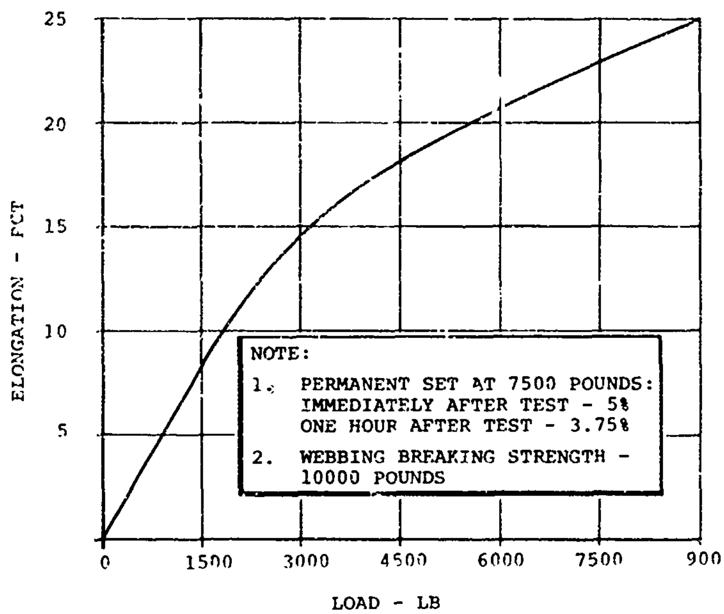

Figure 131. Elongation Versus Load for Type XIX Condition R Nylon Webbing per MIL-W-27265.

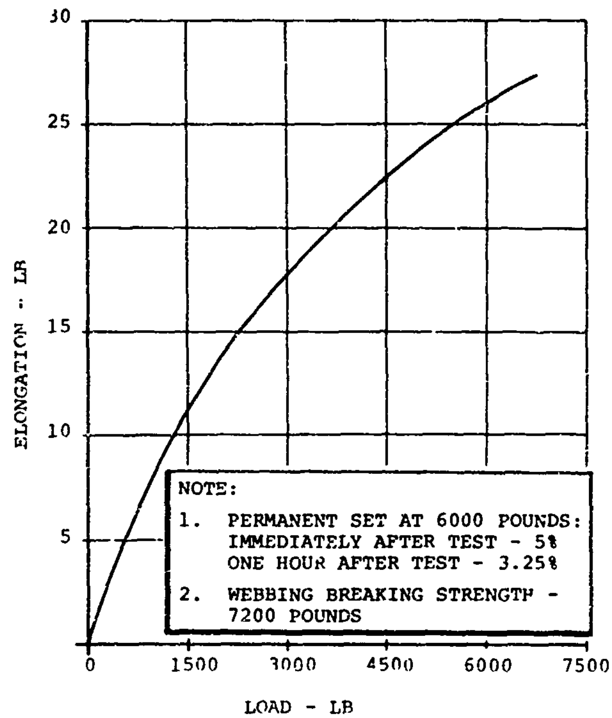

Figure 132. Elongation Versus Load for Type XXII Condition R Nylon Webbing per MIL-W-27265.

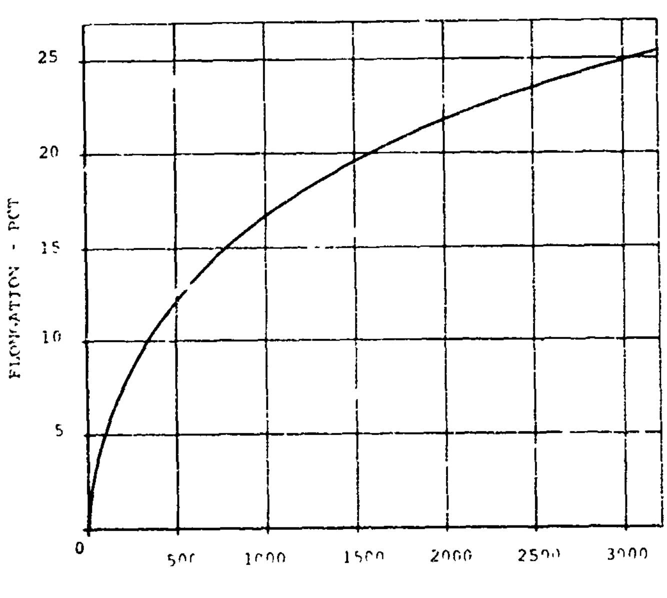

Figure 133. Elongation Versus Load for Type XXV Natural Nylon Webbing per MIL-W-4088.

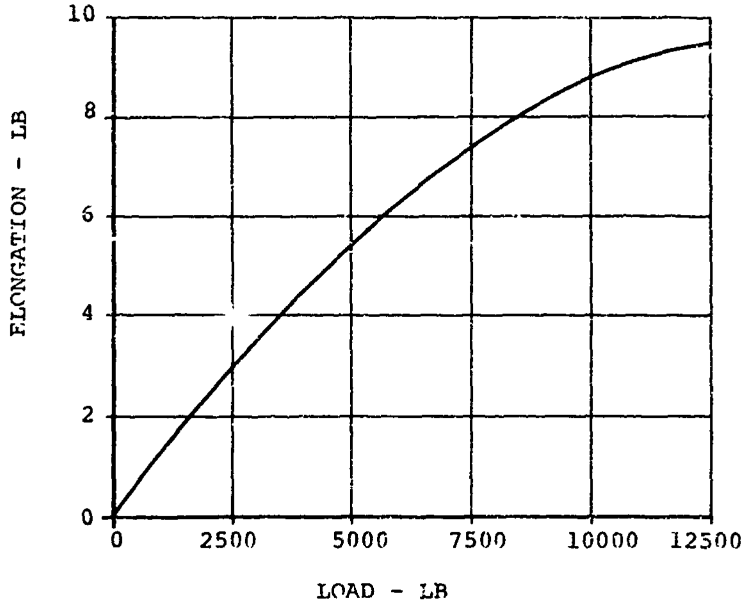

Figure 134. Elongation Versus Load for No. WD 331 Natural Polyester Webbing.

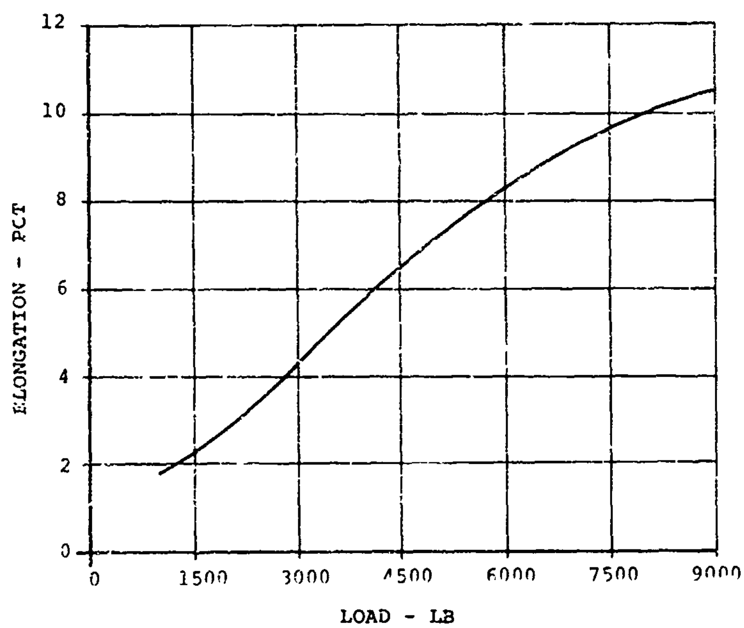

Figure 135. Elongation Versus Load for WD 348 Natural Condition U Polyester Webbing.